TECHNOLOGICAL FORECASTS FOR HARD COPY AND VIDEO DISPLAY COMMUNICATION TERMINALS

Herbert Charles Kaler

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

TECHNOLOGICAL FORECASTS FOR HARD COPY
AND VIDEO DISPLAY COMMUNICATION TERMINALS

by

Herbert Charles Kaler

March 1975

Thesis Advisor: G. L. Musgrave

Approved for public release; distribution unlimited.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Technological Forecasts for Hard Copy and Video Display Communication Terminals		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; March 1975
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Herbert Charles Kaler		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE March 1975
		13. NUMBER OF PAGES 88
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Postgraduate School Monterey, California 93940		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The communication industry is clearly in a state of transition and communication managers faced with decisions about commitments to today's products need to know about possible future changes in the industry. To fulfill this need, this study develops technological forecasts for hard copy and video display communications terminals. Changes in input/output parameters of the terminals, when the changes will occur, and how rapid the

changes will be are estimated. These forecasts are determined by first measuring a limited number of performance parameters such as print rate and transmission speed. Then mathematical models are fitted to the performance parameter data and the trend extrapolated into the future to make predictions. The results of the study indicate that print rates will increase significantly in the next ten years to a level of approximately 2000 characters per second and transmission speeds to a level of approximately 500,000 bits per second for hard copy terminals. Video display terminals show a steeper increase with transmission speed levels of 1.5 Mbps predicted in the next five years. Also, the print rate per dollar and transmission speed per dollar for these terminals will show rapid increases in the next ten years. This study indicates that hard copy terminals and video display terminals are on the verge of significant changes that communications managers should take into consideration in their procurement and design decisions.

Technological Forecasts
for
Hard Copy and Video Display Communication Terminals

by

Herbert Charles Kaler
Lieutenant, United States Navy
B.S., University of Notre Dame, 1969

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
March 1975

ABSTRACT

The communication industry is clearly in a state of transition and communication managers faced with decisions about commitments to today's products need to know about possible future changes in the industry. To fulfill this need, this study develops technological forecasts for hard copy and video display communications terminals. Changes in input/output parameters of the terminals, when the changes will occur, and how rapid the changes will be are estimated. These forecasts are determined by first measuring a limited number of performance parameters such as print rate and transmission speed. Then mathematical models are fitted to the performance parameter data and the trend extrapolated into the future to make predictions. The results of the study indicate that print rates will increase significantly in the next ten years to a level of approximately 2000 characters per second and transmission speeds to a level of approximately 500,000 bits per second for hard copy terminals. Video display terminals show a steeper increase with transmission speed levels of 1.5 Mbps predicted in the next five years. Also, the print rate per dollar and transmission speed per dollar for these terminals will show rapid increases in the next ten years. This study indicates that hard copy terminals and video display terminals are on the verge of significant changes that communications managers should take into consideration in their procurement and design decisions.

TABLE OF CONTENTS

I. BACKGROUND-- 10

A. INTRODUCTION-------------------------------------- 10

B. TECHNOLOGICAL FORECASTING------------------------ 13

C. FIGURES OF MERIT---------------------------------- 16

D. FLOYD MODEL--------------------------------------- 18

E. BLACKMAN MODEL------------------------------------ 21

F. COMPARISON OF FLOYD AND BLACKMAN MODELS------ 25

G. THE SCIENCE-TECHNOLOGY-UTILIZATION MODEL----- 27

H. PROBABILITY OF OCCURRENCE ------------------- 30

II. DATA AND CALCULATIONS------------------------------- 32

A. INTRODUCTION-------------------------------------- 32

B. HARD COPY TERMINALS------------------------------ 33

1. Science Level for Hard Copy Terminals---- 40

a. Print Rate Science Level------------- 40

b. Transmission Speed Science Level----- 41

2. Technology Level Calculations for Hard Copy Terminals---------------------------- 42

a. Technology Level for f = Print Rate-- 42

b. Technology Level for f = Transmission Speed--------------------------------- 44

c. Technology Level for f = Print Rate / Purchase Price------------------------ 47

d. Technology Level for f = Transmission Speed / Purchase Price----------------49

3. Utilization Level Calculations for Hard Copy Terminals---------------------------51

a. Utilization Level for f = Print Rate-- 51

b. Utilization Level for f = Transmission Speed-- 52

c. Utilization Level for f = Print Rate / Purchase Price------------------------- 54

d. Utilization Level for f = Transmission Speed / Purchase Price----------------- 56

C. VIDEO DISPLAY TERMINALS------------------------ 57

1. Science Level for Video Display Terminals-- 66

2. Technology Level for Video Display Terminals---------------------------------- 66

a. Technology Level for f = Transmission Speed------------------------------------ 66

b. Technology Level for f = Maximum Video Display Positions / Purchase Price----- 68

c. Technology Level for f = Transmission Speed / Purchase Price----------------- 68

3. Utilization Level for Video Display Terminals---------------------------------- 71

a. Utilization Level for f = Transmission Speed------------------------------------ 71

b. Utilization Level for f = Maximum Video Display Positions / Purchase Price----- 72

c. Utilization Level for f = Transmission Speed / Purchase Price----------------- 72

III. CONCLUSIONS-- 75

LIST OF REFERENCES------------------------------------ 83

BIBLIOGRAPHY-- 86

INITIAL DISTRIBUTION LIST------------------------------ 88

LIST OF TABLES

I. Overall List of Hard Copy Terminals--------------- 37

II. List of Significant Hard Copy Terminals (Print Rate)------------------------------------ 43

III. Hard Copy Terminal Print Rate Predictions (Technology)------------------------------------ 44

IV. List of Significant Hard Copy Terminals (Trans. Speed)------------------------------------ 45

V. Hard Copy Terminal Trans. Speed Predictions (Technology)------------------------------------ 46

VI. List of Significant Hard Copy Terminals (Print Rate/Purchase Price)------------------------------ 47

VII. Hard Copy Terminal Print Rate / Purchase Price Predictions (Technology)------------------------- 49

VIII. List of Significant Hard Copy Terminals (Transmission Speed / Purchase Price)------------ 49

IX. Hard Copy Terminal Transmission Speed / Purchase Price Predictions (Technology)---------- 51

X. Hard Copy Terminal Print Rate Predictions (Utilization)------------------------------------ 52

XI. Hard Copy Terminal Transmission Speed Predictions (Utilization)------------------------------ 54

XII. Hard Copy Terminal Print Rate / Purchase Price Predictions (Utilization Level)------------------ 55

XIII. Hard Copy Terminal Transmission Speed / Purchase Price Predictions (Utilization)------------------ 57

XIV. Overall List of Video Display Terminals---------- 61

XV. List of Significant Video Display Terminals (Trans. Speed)------------------------------------ 66

XVI. Video Display Terminal Transmission Speed Predictions (Technology)------------------------- 68

XVII. List of Significant Video Display Terminals (Trans. Speed / Purchase Price)------------------ 69

XVIII. Video Display Terminal Transmission Speed / Purchase Price Predictions (Technology)---------- 70

XIX. Video Display Terminal Transmission Speed Predictions (Utilization)------------------------- 72

XX. Video Display Terminal Transmission Speed / Purchase Price (Utilization)--------------------- 74

XXI. Overall Trend Predictions------------------------ 76

LIST OF FIGURES

1. Plot of Floyd Model---------------------------------- 21

2. Plot of Blackman Model------------------------------- 24

3. Plot of Floyd and Blackman Models------------------- 25

4. Science-Technology-Utilization Model--------------- 28

5. Sample Plots for Regression Analysis--------------- 33

6. Input/Output Model for Hard Copy Terminals--------- 36

7. Hard Copy Terminals Print Rate Technology Level---- 44

8. Hard Copy Terminals Transmission Speed Technology Level--- 46

9. Hard Copy Terminals Print Rate / Purchase Price Technology Level---------------------------------- 48

10. Hard Copy Terminals Transmission Speed / Purchase Price Technology Level------------------------------ 50

11. Hard Copy Terminals Print Rate Utilization Level--- 52

12. Hard Copy Terminals Transmission Speed Utilization Level-- 53

13. Hard Copy Terminals Print Rate / Purchase Price Utilization Level---------------------------------- 55

14. Hard Copy Terminals Transmission Speed / Purchase Price Utilization Level------------------------------ 56

15. Input/Output Model for Video Display Terminals----- 59

16. Video Display Terminals Transmission Speed Technology Level---------------------------------- 67

17. Video Display Terminals Transmission Speed / Purchase Price Technology Level------------------- 70

18. Video Display Terminals Transmission Speed Utilization Level---------------------------------- 71

19. Video Display Terminals Transmission Speed / Purchase Price Utilization Level------------------ 73

I. BACKGROUND

A. INTRODUCTION

The communication terminal industry is clearly in a state of transition and communications managers faced with decisions about commitments to today's products need to know about possible future changes in the industry. To fulfill this need, this study develops technological forecasts for hard copy and visual display communications terminals. Changes in input/output parameters of the terminals, when the changes will occur, and how rapid the changes will be are estimated. These changes in terminal parameters are determined by applying the technological forecasting technique of trend extrapolation that estimates a trend from past data and projects the trend into the future. The results are presented in both graphical and tabular form to make them useful from the standpoint of the communications manager in making decisions and tradeoffs. As a background to the approach used in determining the results, this chapter will present a brief introduction to the topic of technological forecasting, discussing the need for technological forecasts in the communication terminal industry and how the forecasting technique of trend extrapolation supplies these needed forecasts. Also, the mathematical models and the step-by-step approach used in the study are discussed as a background for the actual calculations in chapter two.

First, what is "technology"? Technology is one of the most powerful forces in our society today, especially in the business sector. In this context, technology refers to the engineering practices used in industry, whether physical such as tools, machines and materials, or procedural such as heat processes for metals and computer software. The direction that changes in technology take and how this direction influences our lives are very important concepts for the modern day businessman, but "not one businessman out of a thousand attempts to forecast technology."[1] This is changing and with the introduction of technological forecasting as a course in the Harvard Business School in the early 1960's and the increase in technological forecasting literature in the past ten years[2] a new awareness of methods for forecasting the future is evident. The communication manager has a very definite need to forecast future characteristics of communication equipment if he is to build the most efficient system for the least cost.

How can predictions of hard copy and video display communication terminals help the communication manager? To answer this question, one only has to look at the problem of obsolescence. Considering the rapidity of introduction of superior technical successors, the problem of obsolescence occurring faster than planned, must be considered in the tradeoffs managers make in communication systems design. Each succeeding technological concept tends to have a

shorter marketplace life than its predecessor, because of prompt challenge from a new and superior technology.[3] The electronic components industry in its progress from tubes to transistors and now to integrated circuits is a good example of this rapid technology change.[4] The predicted characteristics from this study show how much communication terminal technology is changing and when a rapid increase is most likely to occur.

With these predicted values and the timing of rapid changes in the technology, a communications manager can program his procurement schedule to ensure that his system is the most current for the least life cycle cost. That is, he looks at the cost of a component over its whole life and not just the original purchase price. No longer does the manager have to rely on intuition to determine the market place life of a component, but can use forecasts to determine a value. Then, in considering the tradeoffs between buying a state of the art technology at a higher purchase price or a minimum acceptable technology at a lower price, the market place life determination will put the tradeoff decision into perspective. The dollars that are saved in the purchase of the minimal acceptable technology might be lost in having to replace the component sooner than the more expensive state of the art technology.

B. TECHNOLOGICAL FORECASTING

To obtain the needed future projections, today's managers can turn to technological forecasting techniques; but to do this, a manager must understand technological forecasting. In simple terms, technology forecasting can be defined as the application of scientific methods to determine when and by how much measurable parameters of a technology will change. The scientific methods can include statistics, simulation, modeling or even brainstorming of informed opinions that will give results. Altogether, there are more than twenty forecasting techniques in use today[5] but for this study only trend extrapolation will be used. The reason for the selection of this method is "its relative simplicity, its ability to provide quantification, its long history of use in industry and the modality of the proposition that past history is a good guide to the future."[6]

The extrapolation of a trend or cycle, as Dr. S. C. Gilfillan, a noted futurologist states, is one of the most fundamental and simple methods of prediction.[7] Usually, a trend is a better predictor than a cycle in technological advances because a technology progresses from a new idea to a perfected advanced item. That is, progress in a technology may move fast or slow, but it will always be increasing or staying at the same level. A technology level once reached does not usually have to be reinvented each time it is needed.

What then is trend extrapolation based on and what are its limitations? "The fundamental assumption of a trend extrapolation is that the complex set of conditions which have prevailed in the past and have governed the historical rate of technological progress will not in the future change to a degree which will preclude extrapolation."[8] That is, if a manager can say that his technology has followed a definite trend in its development and that the forces that caused this development will not change drastically in the near future, then trend extrapolation can be applied to this technology. This is the case with hard copy and video display communication terminals.

There are two important points in the fundamental assumption of trend extrapolation that need further discussion. First, the object or device under development must be adequately characterized by a limited number of parameters. The reason for this is that with limited parameters one can minimize the complex interactions between parameters. Since each parameter of a technology must share the time of the engineers and the resources of the company, fewer parameters mean fewer tradeoffs of resources. Second, historical continuity must prevail. This means that devices appearing at different times can be characterized by the same set of parameters and that subsequent development can begin where prior development ended.[9] Discontinuities are not allowed in trend extrapolation.

In selecting the limited number of parameters of a technology, simple input/output diagrams are used, but it should be noted at this point that emphasis on outputs (performance parameters) over inputs (technical parameters) favors the assumption of continuity. In selecting a new technology, a buyer is more interested in performance parameters, such as speed and capacity, than technical parameters, such as the actual hardware technical specifications, once the minimum acceptable technical specifications are met. A buyer also has to make sure that he obtains a profitable return on previous investments which leads to a conservative attitude toward buying new technologies before the old technology is obsolescent. Therefore, because of this preference toward performance parameters and the conservative buying attitude, any rapid increase in performance (output) parameters would be countered by the conservative buying and show a smooth advancement over time.

Trend extrapolation has limitations and they are in both the predictions themselves and the accuracy of the predictions. The measure of technological advances that trend extrapolation gives us is only intended to capture mainstream trends. It is not able to identify fine differences and does not consider causation.[10] For this reason, varying degrees of uncertainty are inherent in this method, but in the basic assumption and the lack of analysis of causation, and

therefore it is essential that a quantitative measure of the probability that the trend will continue be provided.

If the basic assumption is accepted, a limited number of parameters are identified and continuity prevails, then one should be able to fit a mathematical model to past data and then extend this model into the future to obtain predictions of a technology. This is what this study does for hard copy and video display terminals. Before proceeding to discuss the two mathematical models for trend extrapolation used in this study and an uncertainty measure for the continuation of the trend, the term "figure-of-merit" must be defined and its use in measuring trends explained.

C. FIGURES-OF-MERIT (f)

"The measure of technological change is a problem of quantifying intuitive feelings."[11] A unit of measure is needed to apply the methodology of trend extrapolation to these feelings. To do this technological parameters can be described in terms such as thrust to weight ratio for aircraft engines, numbers of characters printed per dollar for terminals or core capacity per dollar for computers and labeled as figures-of-merit (f). The term "figure-of-merit" can be applied to any measurable technical parameter or any combination thereof (addition, multiplication, etc.). This flexibility allows the researcher to look at several figures-of-merit to find the one that is the most responsive to changes in the technology under study.

What changes can one expect in typical figures-of-merit and what do these changes tell us? First of all, one can expect the rate of increase for technological figures-of-merit to increase with increases in rewards for achieving performance improvements. That is, if an urgent need exists and rewards are offered, one can expect to see this technological advance appear before it would otherwise occur. Second, "with other things being equal, improvements in the technological state-of-the-art would be expected to be a decreasing function of the extent of the resource commitment required to improve the state-of-the-art. Third, it would be expected that different areas of technology would exhibit different growth characteristics because of variations in the availability of trained personnel, facilities, glamour, social relevance, etc."[12] Lastly, one can expect that "when design features are frozen in hardware, technology growth cannot take full advantage of newly developed techniques."[13]

Once figures-of-merit for a technology are selected and the changes one can expect are identified, a mathematical model can be developed to simulate the trend. Two mathematical models have been proposed in recent years to quantify these technological trends in an effort to make predictions. These two models will be briefly discussed to give a background for understanding their application to the prediction of communication terminal trends.

D. FLOYD MODEL

The projection of figures-of-merit for significant parameters in a technology was used by Dr. A. L. Floyd in 1968 as an approach to technological forecasting. Floyd in his studies for Lockheed Aircraft Corporation developed a technique based on the mathematical simulation of the development process and its effect on industry.[14]

Floyd's basic approach, once a typical figure-of-merit (f) was chosen, was to "calculate the probability of improving the figure-of-merit through applied effort."[15] From this analysis Floyd was able to make an assumption to give a first general approximation. The assumption was that "the rate of change of successful techniques available to improve a figure-of-merit is proportional to the number of techniques absorbed to achieve the value of the figure-of-merit,"[16] or in equation form:

$$\frac{\Delta X}{\Delta f} = -k\ (M-X) \qquad (1)$$

where X = the number of techniques available that would be successful

f = figure-of-merit

k = constant

M = Total number of possible techniques or approaches that could be considered.

That is, the increase in f associated with the using up of successful techniques (X) is inversely related to the number of successful techniques already used up (M-X).

Equation (1) was then integrated between X=X and X=0 and between f and the limiting value of f, defined as F. F is an important value here because it sets the upper limits for the prediction. From this integration, a relationship for X/M was found as

$$\frac{X}{M} = 1 - \exp\left[-k(F-f)\right]. \qquad (2)$$

Noting that equation (2) is the probability of improving the figure-of-merit by one worker in one try, Floyd then expanded this to include an average number of workers W with N attempts per unit of time and showed the probability of exceeding a given f in a time span Δt as

$$P(f,\Delta t) = 1 - \left(1 - \frac{X}{M}\right)^{\bar{N}\bar{W}(\Delta t)} \qquad (3)$$

Then by substituting equation (2) into equation (3) and putting into integral form the following was obtained

$$P(f,t) = 1 - \exp\left[-(F-f)\int_{-\infty}^{t} k\bar{N}\bar{W}\,dt\right] \qquad (4)$$

Floyd then noted that the introduction of new competitive technologies with its shift of workers would have an effect on equation (4), so he introduced a first approximation for this effect as

$$W = (f - f_c)W_0(t) \qquad (5)$$

where f_c = figure-of-merit for the competitive technology

and $W_o(t)$ = the relatively constant growth of total workers available.

Placing this value in equation (4) yielded

$$P(f,t) = 1 - \exp\left[-(F-f)\int_{-\infty}^{t}(f-f_c)T(t)dt\right] \quad (6)$$

where $T(t) = k(t).N(t).W_o(t)$ (7)

"For trend forecasting we are interested in keeping the probability P(f,t) constant at the 50 per cent value and determining how the figure-of-merit varies with time."[17] With this requirement equation (7) was integrated and evaluated by separation of variables. Thus

$$P(f,t) \equiv 0.5 = 1 - \exp\left[\frac{-0.6931(C_1t + C_2)}{Y + \ln(Y-1) + C_2}\right] \quad (8)$$

where $Y = \dfrac{1 - f_c/F}{1 - f/F}$ (9)

C_1, C_2 are constants

t = time

Equation (8) was then put in a simple form by setting P(f,t) equal to a constant and taking the logarithm of both sides. Thus

$$Y + \ln(Y-1) = C_1t \quad (10)$$

This is the form of Floyd's model that will be used in this study and a plot of this equation is shown below in Figure 1.

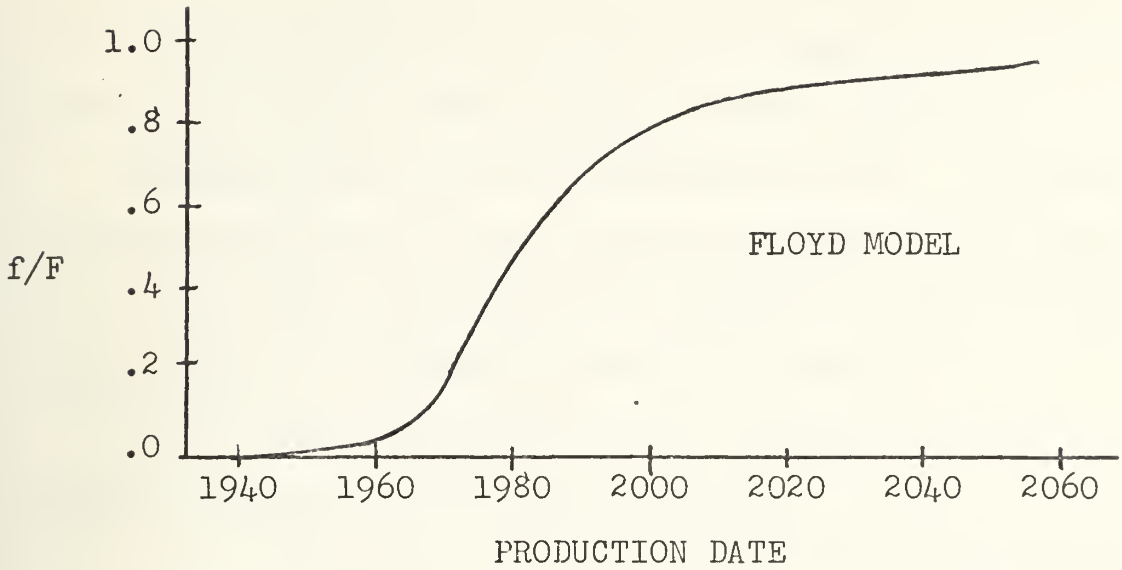


Figure 1. Plot of Floyd Model.

To use this model three values must be determined. First, the values of F and f_c must be estimated and then the constant C_1 must be determined by using at least two historical data points. If more historical data is available, a best fit value of C can be used. With the values of C calculated, a model curve can be drawn and later occurring data points can be used as a comparison check to ascertain whether the curve is a good fit for this data.

E. BLACKMAN MODEL

After Floyd's model, another mathematical model for trend extrapolation was introduced by A. Wade Blackman, Jr., to enable projections of technological performance figures-of-merit to be made.[18] These figures-of-merit as discussed earlier are merely performance parameters which are representative of the state-of-the-art in an area of concern, such

as print rate, transmission speed or number of characters per dollar in the communication terminal industry.

Blackman developed his mathematical model by hypothesizing that the change in the figure-of-merit is a function of:

1. the figure-of-merit obtained at time t divided by the maximum attainable value, i.e., f(t)/F.

2. the perceived payoff or reward, R, associated with an increase in the figure-of-merit.

3. the size of the investment, I, or the extent of commitment of resources required to improve the figure-of-merit.[19]

This mathematical model can then be shown in equation form as:

$$\Delta f(t) = \pi \left[f(t)/F, R, I \right] \tag{11}$$

Then by approximating this function with a Taylor expansion as

$$\begin{aligned} \Delta f(t) = C_1 + C_2 \frac{f(t)}{F} + C_3 R + C_4 I + C_5 \frac{R f(t)}{F} + C_6 \frac{I f(t)}{F} \\ + C_7 RI + C_8 R^2 + C_9 I^2 + C_{10} \left[\frac{f(t)}{F} \right]^2 \end{aligned} \tag{12}$$

and if third and higher order terms are dropped, C_{10} is assumed equal to zero and equation (12) is substituted into equation (11), one obtains

$$f(t+1) - f(t) = \frac{df(t)}{dt} = \left[F - f(t) \right] \left[\Gamma + \alpha \frac{f(t)}{F} \right] \tag{13}$$

where Γ is the sum of all terms in equation (12) not containing f(t)/F and α is the sum of all terms involving f(t)/F.

A solution was obtained to equation 13 as

$$f(t) = \frac{F\{\exp[C+(\Gamma+\alpha)t] - \Gamma/\alpha\}}{1+\exp[C+(\Gamma+\alpha)t]} \qquad (14)$$

where C is a constant of integration.

Then Blackman applied the boundary condition that f(t) must approach zero as time goes backward. Thus

$$\lim f(t) = 0 \qquad (15)$$

which requires Γ to be zero. For the second boundary condition an additional constraint was written as

$$f(t') = F_0 \qquad (16)$$

where $t' \equiv t - t_1$ (17)

with t_1 defined as the year in which an initial figure-of-merit, F_0 occurred.

Applying these two contraints a general equation was found to be in the form of

$$\ln\left[\frac{f}{F-f}\right] = C_1 + C_2 t \qquad (18)$$

where C_1 and C_2 are constants. A plot of this equation is given in Figure 2 below.

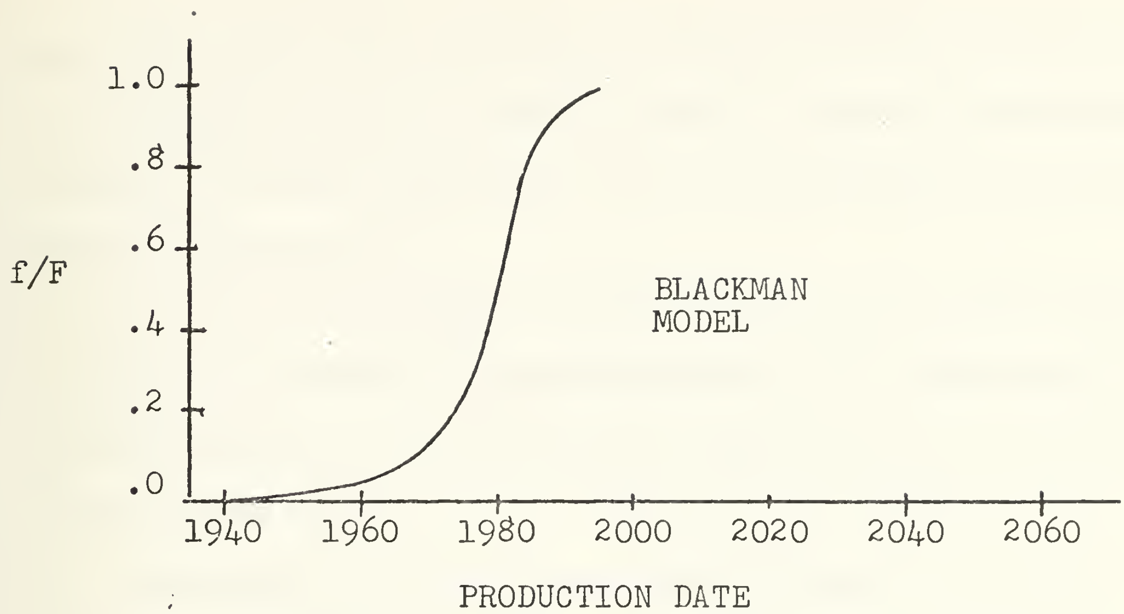


Figure 2. Plot of Blackman Model.

This model, as Blackman shows in his studies of the dynamics of the electrical utility and automotive industries, proves to be very good at predicting technological advances and exhibits very high correlations to later data points.[20]

To apply his model to a sample set of data, Blackman evaluated his two constants from two data points which occurred early in the technological development. If more historical data is available, best fit values of C_1 and C_2 can be used. Then with the constants determined, a plot of equation (18) was used to predict the trend. A comparison of this curve with future figures-of-merit occurring later in time was then undertaken to show how well the model was predicting.

It must also be pointed out here, and was stressed by Blackman, that although it was conceptually easy to apply

his model, the lack of historical data on the perceived payoff of technological advances and the required investments needed to achieve advances in the technology made it difficult in practice.[21]

Floyd's and Blackman's models are used in this study to evaluate a variety of figures-of-merit for communication terminals, and to predict future capabilities in communication terminals.

F. COMPARISON OF FLOYD AND BLACKMAN MODELS

Is one model better than the other or are both good predictors? If one graphs both models on the same graph (See Figure 3 below), it can be seen that in the early period of development, both curves are similar; but as one approaches the upper limit, Floyd's model predicts a slower rate of development than Blackman's model.

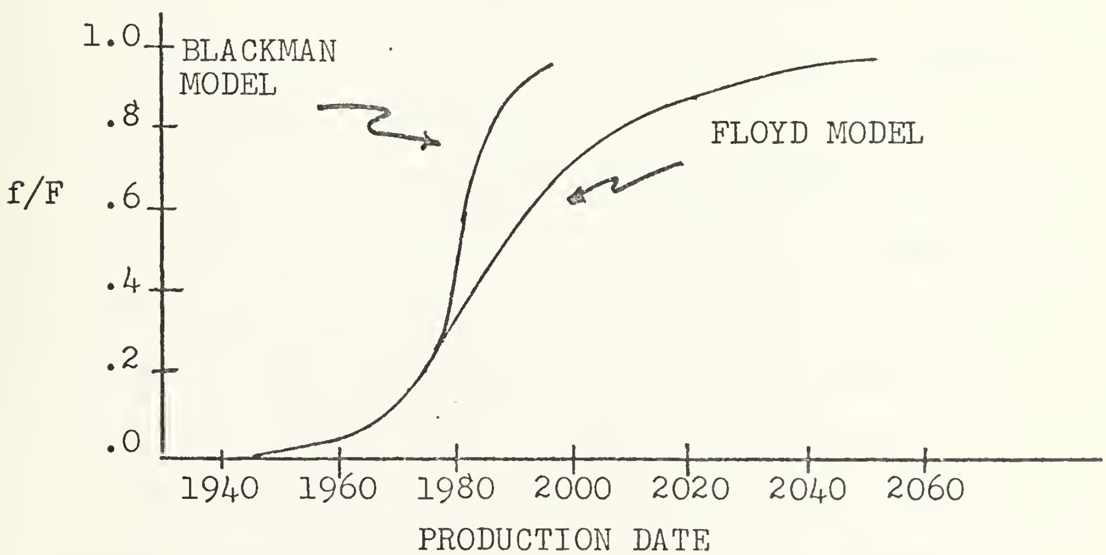


Figure 3. Plot of Floyd and Blackman Models.

Even though both models can be applied to the same data and graphed on the same paper, is a comparison really fair? The key point in answering this question is to keep straight the assumptions that each model is derived from. Floyd's equation is a function of techniques for advancement, manpower available, number of attempts to find a new technique and the effect of competitive industries on a functional capability designated as f. Blackman's equation, on the other hand, is a function of the ratio of f/F, the perceived payoff or reward for an increase in f and the size of the investment or commitment of resources. Therefore, each model is trying to capture a trend by looking at different but related parameters and the only conclusion one can obtain from a comparison is whether the assumptions used in each model capture the trend behind the particular technology being studied. Both of them, either of them, or none of them may be responsive to the complex set of conditions that drive a particular technology.

Both models have been applied successfully by their authors,[22, 23] so their ability to predict, if their assumptions capture the trend, is not in question. Therefore, in this study a direct comparison of the two models will not be attempted but instead each one will be applied in every case to give two predictions and only when specific reasons why the assumptions of a model do not hold can be shown, will the results of that model be discarded.

Now that the two models have been introduced a framework is needed to present the results of applying these models to communication terminal data. For this purpose, the Science-Technology-Utilization model is presented.

G. THE SCIENCE-TECHNOLOGY-UTILIZATION MODEL

Applying Floyd's and Blackman's models to a set of data will result in predictions but depending on which data points are selected to calculate the equation constants, these predictions will be quite different. For this reason a system framework is necessary to put these predictions into perspective.

The Science-Technology-Utilization model[24] (See Figure 4 below) provides such a framework for presenting the technology predictions in perspective. This model is based on the idea that the transfer of technologies is one aspect of the wider process of technological innovation.[25] The three areas of the model (Science, Technology and Utilization) provide measuring stages for innovation and it is the movement between these stages and within the stages themselves that trend extrapolation measures. Therefore, depending on how the Floyd and Blackman equations are applied, measurement of these three levels is possible.

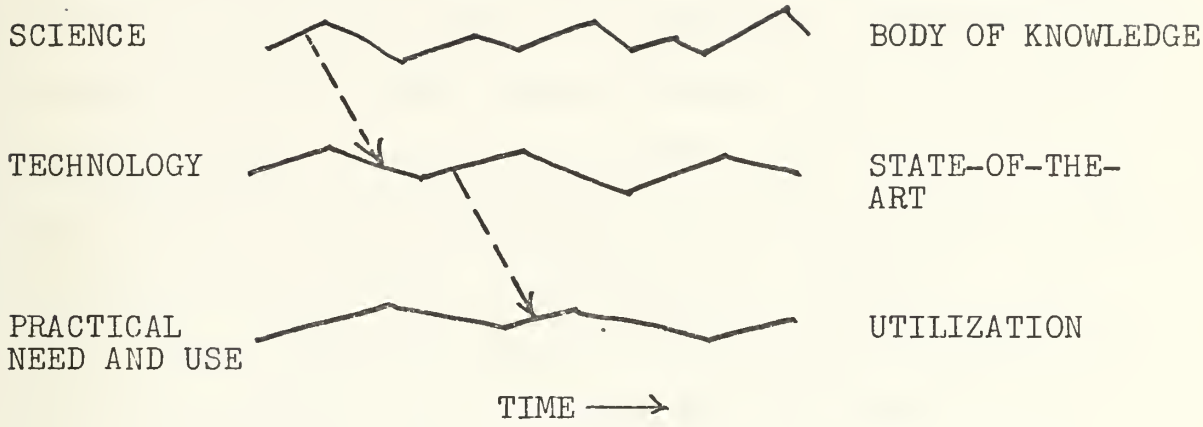


Figure 4. Science-Technology-Utilization Model.

The Science level or highest level will be the most difficult level to measure. This level encompasses scientific findings of phenomena, laboratory feasibility studies such as "bread board" models, actual operating prototypes and even production items that can be adapted to advance the technology under study. In other words, this level includes the whole body of knowledge from which technology advances can come. This level can also be very volatile when breakthroughs occur. Some of these breakthroughs will drop to the technology level as they are produced, while others, because of high production costs, will just stay in the scientific body of knowledge for possible later use. In this study there will be no attempt to forecast future Science levels because of the difficulty in quantifying the data for this level. Instead, this level will just be estimated from current literature to show the gap between this level and the technology level.

The Technology or State-of-the-Art level is easier to measure and, by using dates as a parameter, technology can be fixed in time. "This stage represents not only technical and design adequacy, but economic feasibility."[26] In other words, the new technology must be good enough to make the buyer give up what he already has to obtain it. For setting this level only devices that incorporate new ideas from the scientific body of knowledge are looked at to measure how well technology is incorporating scientific ideas into production models.

The Practical or Utilization level is a measure of the extent that the market is following the technology. This is the level where widespread acceptance is measured. For this study widespread acceptance is defined to mean the level of the regression line for all production models. This should tend to average out the introduction of state-of-the-art devices with the continued production of new models of past terminals and give a good estimate of this level. Devices in this level have proved that they are technically and economically superior to the models they have replaced. As new devices are accepted, this utilization level will move up, but at a slower pace than the technology level.

Now that the two mathematical models and the framework for their use have been discussed, only the question of how good are these predictions remains. To answer this question

of goodness, probability calculations will be introduced and later applied to give probabilities of the trend continuing.

H. PROBABILITY OF OCCURRENCE

Because uncertainty of future technologies appearing when predicted is an inherent characteristic of all trend projections, it is essential that trend forecasts contain estimates of the probability that the trend projections will in fact occur.[27] Floyd in his model includes a measure of the uncertainty in his trend probability calculations.[32] During the development of his model, he noted that his model represents estimated values at a 50 percent probability level. That is

$$P(f,t) = 0.5 \tag{19}$$

By assuming this, he was able to apply the conditional probability equation (20) to determine the probability of the trend occurring at a later time as

$$P(f/f_0, t) = \frac{P(f,t)}{P(f_0,t)} \tag{20}$$

where f_0 = is the latest data point.

Then Floyd noted that by using equation (8) to solve for $P(f_0,t)$, one obtained

$$P(f_0,t) = 1 - \exp\left[-0.6931(F-f_0)(f_0-f_c)(C_1 t + C_2)\right] \tag{21}$$

where t is the new time. He then noted that $P(f_0, t_0)$ is 50 percent and using equation (10) he obtained

$$P(f_0,t) = 1 - 0.5\, \exp\left\{-(F-f_0)(f_0-f_i)\left[y + \ln(y-1) - y_0 - \ln(y_0-1)\right]\right\} \quad (22)$$

where y = value from trend curve at new time

y_0 = value from trend curve at time corresponding to the figure-of-merit f_0.

In this study equation (22) is applied to the predictions and with the conditional probability equation (20), the probability that the trend will occur with time is calculated.

II. DATA AND CALCULATIONS

A. INTRODUCTION

This chapter presents the results from the application of the models discussed in the background chapter. For ease of presentation, the Data chapter is divided into two parts: Hard Copy Terminals and Video Display Terminals. A short background of each area is then discussed and the data set for each area presented. From the data set, technology and utilization levels are calculated using the models and the science level is estimated.

In presenting just the results in table and graph form, many steps may not be clear to the reader. For this reason, the method used is outlined here to negate the need to repeat it for the numerous sets of results. For each area, figures-of-merit to be analyzed are developed and presented in the brief discussion of the two types of communication terminals. These figures-of-merit are then applied to the data set and their values calculated. With the estimation of the science level, a value is given to F, the limiting value of f. Now with the values of f, F and the corresponding production dates, plots are made of $\ln\left(\frac{f}{F-f}\right)$ and $\left[\left(\frac{F}{F-f}\right) + \ln\left(\frac{f}{F-f}\right)\right]$ versus the production dates for Blackman's and Floyd's models respectively. Typical graphs are shown in Figure 5 below.

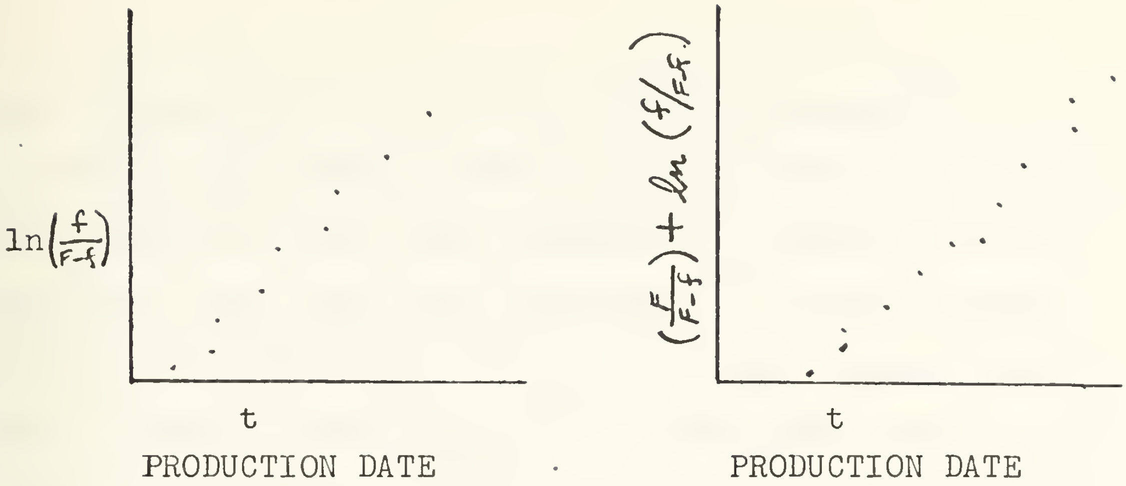


Figure 5. Sample Plots for Regression Analysis.

It should be noted here that in applying Floyd's model, the value of f_c is assumed to be zero for the calculations, because of the difficulty in assigning a value to f_c.

On the graphs in Figure 5, a regression line of the logarithmic functions on t is calculated to determine the constants of the models. With these constants the models are graphed as in Figures 1 and 2 and the predictions for future years calculated. With each prediction is a trend probability that is calculated by using the latest significant terminal for the technology level and the latest terminal that falls on or near the overall regression line for the utilization level. With these values and equation (22), the trend probabilities are calculated. This probability tells us the probability that the trend will occur with time.

B. HARD COPY TERMINALS (TELETYPEWRITERS)

In the early 1960's there existed a need for a convenient, low-cost means of remote communication with the computer.

The teletypewriter (or teleprinter), a communication-oriented typewriter then heavily used in message switching networks, was a natural as the first man/machine interface for the computers. The reason for the adoption of the teletypewriter in the first days was for the simple reason that no other suitable device existed.[28] To determine how teletypewriters have changed in the years since their adoption as links to the computer and what they will be like in the future, a detailed analysis of the important characteristics needs to be undertaken.

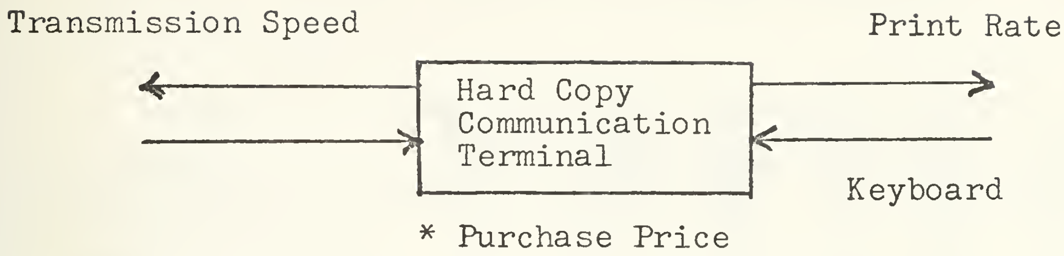
To start this analysis one must first decide on a definition of what a teletypewriter terminal is. For the analysis in this thesis, a teletypewriter terminal will be defined as any device that combines a keyboard, printer and data communication interface. This does not include receive only terminals. Also, the term "Hard Copy Terminal" will be used to mean teletypewriter, teletype, teleprinter, typewriter terminal or any other hard copy communication terminal that meets the above definition.

In applying the two mathematical models for trend extrapolation to hard copy terminals, quantifiable performance parameters must be identified for use in developing figures-of-merit. Referring back to the three key areas (keyboard, printer and communication interface) of the hard copy terminal definition, print rate can be used to measure printer efficiency and transmission speed used to measure communication

interface efficiency. Keyboard efficiency, though, is a function of the operator and for this analysis an average operator will be assumed. Also, the economic parameter of purchase price will be used as a third parameter to determine cost trends.

The transmission speed of the terminal is specified in bits per second and is usually limited by the speed of the printer or other I/O device unless the terminal contains an internal buffer. Buffered operation permits printing to be performed at the rated speed of the printer, although the transmission speed may be much greater.[29] Most typewriter terminals are unbuffered due to cost considerations and, therefore, operate at low transmission speeds. The print rate on the other hand specifies the maximum rated printing speed of the printer in characters per second. Some terminals offer more than one rated speed to facilitate matching the communication characteristics of the remote device. In this study only the maximum print speed is considered because measurement of improvement in print speed is desired.

In applying the models to hard copy communication terminals, the terminals will be looked at as a simple input/output model (See Figure 6 below). From this model, four parameters can be defined to be used as figures-of-merit and they are listed below the diagram.



1. Print Rate
2. Transmission Speed
3. Print Rate / Purchase Price (ave)
4. Transmission Speed / Purchase Price (ave)

*Average purchase prices are used.

Figure 6. Input/output model for hard copy terminals.

Using the definition of hard copy terminals, a list of terminals was compiled from DATAPRO 70, THE EDP BUYERS BIBLE.[30] Table I below lists all the hard copy terminals compiled and gives their important parameters. Only terminals with print rate, transmission speed, purchase price, and production date were considered.

TABLE I. OVERALL LIST OF HARD COPY TERMINALS

MODEL	PRINT RATE	TRANS SPEED	PURCHASE PRICE MAX	MIN	AVE	PROD. DATE
1. Teletype Model 33	10	110	1060	595	828	1962.00
2. Teletype Model 35	10	110	3598	1578	2588	1962.00
3. Data Access System DCT 500	30	300	6000	3705	4853	1965.00
4. Teletype Model 37	15	150	4995	2200	3598	1966.00
5. CTSI Execuport 300	30	300	3190	3190	3190	1968.00
6. IBM MT/ST	15	135	10350	8550	9450	1968.00
7. Olivetti TE 318/1	10	110	2330	2330	2330	1969.00
8. Data Acess System 75/4125	30	300	5600	2780	4190	1969.00
9. General Electric Termi Net 300	30	300	6990	2080	4535	1969.50
10. Harris CSI Cope 1030	15	134	4945	2580	3763	1969.50
11. Data Measurements DMC 220	15	150	4450	3000	3703	1970.00
12. Carterfone 300	30	300	1675	1675	1675	1970.00
13. Data Products PortaComm	10	300	3145	1695	2420	1970.00
14. Texas Instruments Model 715	30	134	3000	2540	2770	1970.00
15. Texas Instruments Model 720/730	30	300	2820	2115	2468	1970.00
16. Texas Instruments 721/731	30	300	2205	1660	1933	1970.00
17. Anderson Jacobson AJ 841	15	135	4725	4230	4478	1970.50
18. Univac DCT 500	30	300	6495	3320	4908	1970.50
19. Facit Addo 3851/199	15	150	6000	2500	4250	1971.00
20. Tycom 38	10	110	2350	2350	2350	1971.00
21. Tycom 35/37	15	300	4360	2350	3355	1971.00
22. Texas Instruments Model 725	30	300	3040	2780	2910	1971.00

23.	Trendata Models 900/1000/2000	15	270	7350	2990 5170	1971.00
24.	Carterfone 515	15	150	2000	1750 1875	1971.25
25.	Extel AE Series	30	300	1600	1200 1400	1971.25
26.	Extel AF Series	30	300	2360	1260 1810	1971.25
27.	NCR 260	15	300	5000	1960 3480	1971.25
28.	UNIVAC DCT 1000	30	4800	27745	8300 18022	1971.25
29.	Digital Equipment LA 30	30	300	3195	3195 3195	1971.50
30.	Harris CSI Cope 1040	15	135	2580	2580 2580	1971.50
31.	Anderson Jacobson AJ 630	30	300	4395	2700 3548	1971.75
32.	IBM CMC/ST	15	135	10575	10575 10575	1971.75
33.	Memorex 1280	30	1200	6575	6575 6575	1971.75
34.	Printer Technology Printec 100	100	4800	1080	1080 1080	1971.75
35.	Transcom CT 264	10	110	1430	1300 1365	1971.75
36.	Teletype Model 38	10	110	1496	937 1217	1972.00
37.	Transcom CT 364	10	300	2395	2120 2258	1972.00
38.	Typagraph DP 30	30	300	4500	3500 4000	1972.00
39.	CTSI Execuport 1200	120	1200	5000	5000 5000	1972.00
40.	Computer Devices CDI 930	30	300	2685	2600 2643	1972.25
41.	I/O Devices Series 200	50	300	5000	4000 3000	1972.25
42.	Memorex 1240	60	600	8775	8775 8775	1972.25
43.	Memorex 1242	60	1200	5000	4000 4500	1972.25
44.	General Electric Termi Net 1200	120	1200	8895	4050 6473	1972.75
45.	Data Interface DI 240	240	2400	4700	2300 3500	1973.00
46.	DI AN Controls 9030	30	300	3330	3330 3330	1973.00
47.	Singer International Model 30	30	300	3200	1200 2200	1973.00
48.	Texas Instruments Model 732	14	100	3145	1575 2360	1973.00

49.	Texas Instruments Model 733	30	300	3795	1500	2648	1973.00
50.	Carterfone 1200	10	1200	2485	1885	2185	1973.25
51.	Computer Devices CDI 1030	30	300	4000	3100	3550	1973.25
52.	Data Measurements DMC 400	30	4800	7500	5000	6250	1973.50
53.	Data Terminals Corporation 300	30	300	5000	3400	4200	1973.50
54.	General Comm GSI 300	30	300	4475	4300	4388	1973.50
55.	Compro Corp Model 6000	30	300	6000	4000	5000	1973.50
56.	Compro Corp Model 1030	30	300	3600	2950	3275	1973.50
57.	Compro Corp Model 3500	30	300	1100	1100	1100	1973.50
58.	Scope Data Series 200	240	2400	2055	1800	1925	1973.50
59.	Terminal Communications TC 241	30	1800	5750	5475	5613	1973.75
60.	Facit Addo 4553	15	150	1445	1445	1445	1974.00
61.	Radectron Communications	15	2400	10000	6700	8350	1974.00
62.	Centronics 308	120	9600	3495	2615	3055	1974.25
63.	Data Measurements DMC 442	30	1800	7500	5700	6600	1974.25
64.	Data Terminals Communications Hywriter	30	300	3400	2500	2950	1974.25
65.	NCR 260-5	30	300	2795	2795	2795	1974.25
66.	Data Interface DI 120/T	200	1200	4000	2400	3200	1974.50
67.	Data Measurements DMC 430	30	1200	6000	4000	5000	1974.50

1. Science Level for Hard Copy Terminals

a. Print Rate Science Level

To determine the science level for print rate in terminals, the technology of printers must be looked at. Printers have traditionally been allowed to be large while terminals are expected to be small. For this reason, printers can use new large scale techniques such as electrostatic, ink jet and xerographic printers that give the printer faster print rates than the printing section of a terminal. Therefore, an analysis of printers can set the present science level for terminal print rate and give an upper limit for terminal print rate figures-of-merit.

Printers can be subdivided into two types, impact and non-impact. Impact printers rely on moving mechanical arms and heads to imprint a character on the paper. This dependence on mechanical arms and heads limits the impact printers print rate to around 120 characters per second level.[31] The non-impact printers, on the other hand, have a smaller number of mechanical moving parts and offer much hope for increasing the print rates. Even today, print rates better than 4000 lines per minute are not uncommon.[32] For this reason, the analysis should be focused on non-impact printers.

Non-impact printers on the market today come in many forms. Electrothermal (or thermal) printers, where electronic burning of a special coating on the paper is used to make the character, is the most popular at present,

but equipment using electrostatic, ink jet and xerographic techniques are also being used. In a comparison of printing rates, the electrothermal (up to 130 cps) is the slowest and the xerographic (up to 8000 cps) is the highest with electrostatic (up to 1200 cps) and ink jet (up to 240 cps) in between.[33] Therefore, xerographic printers offer the highest print rates and can be used to set the science level. Also, since xerographic printers in the 8000 cps range are still in the prototype stage, <u>8000 cps will be used as F</u>, the limit for the print rate figures-of-merit, for all calculations in this study.

b. Transmission Speed Science Level

To determine the science level for transmission speed in terminals, the technology of transmission mediums must be looked at. For it is through these mediums that a terminal passes information to a computer or another terminal. It does not matter whether the communication lines are wire, coaxial cable, microwave radio or even satellite, because transmission over the different media is organized in such a way that the channels obtained have largely the same properties - same capacity, same noise level and same error rate.[34] Therefore, an analysis of types of communication lines will set the present science level for transmission speed and give an upper limit for terminal transmission speed figures-of-merit.

Types of communication lines range from subvoice grade (up to 200 bps), through voice grade (up to

9600 with special line conditioning) to wideband grade (up to 1.5 Mbps), with two kinds of availability; public dial up and leased line.[35, 36] Since the science level is concerned with technology in the prototype stage, the analysis can be further focused on just wideband lines. On wideband lines "speeds up to 500,000 bits per second are in use today, and higher bit rates are possible if required."[37] Therefore, the transmission speeds above 500,000 bits per second can be considered in the science level with the 1.5 Mbps setting the present level of prototype activity.

For this study <u>1.5 Mbps</u> will be considered the upper limit for transmission speed figures-of-merit and all calculations involving transmission speed will use this value for F. It is noted here though that the selection of this value for F means that the calculations performed are determining when this value of F will be reached.

2. <u>Technology Level Calculations for Hard Copy Terminals</u>

a. Technology Level for f = Print Rate

To determine where the level of the state-of-the-art is in hard copy terminal print rate, the data set was studied and only terminals with print rate advancements were used as inputs for the determination of the model constants. The significant terminals for print rate are listed in Table II below.

TABLE II. LIST OF SIGNIFICANT HARD COPY TERMINALS (PRINT RATE)

Terminal Number	Model	Print Rate	Production Date
1.	Teletype Model 33	10	1962.00
3.	Data Access System 500/4150	30	1965.00
34.	Printer Technology Printec 100	100	1971.75
39.	CTSI Execuport 1200	120	1972.00
45.	Data Interface DI 240 Series	240	1973.00

The characteristics of these five significant terminals were regressed to calculate the constants for the two models. The resulting equations are:

<u>BLACKMAN</u>: $$\ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$$

$$\widehat{\ln\left(\frac{f}{F-f}\right)} = -22.340 + \underset{(0.162)}{0.253t} \qquad R^2 = 0.960$$

<u>FLOYD</u>: $$\left(\frac{F}{F-f}\right) + \ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$$

$$\widehat{\left(\frac{F}{F-f}\right)} + \widehat{\ln\left(\frac{f}{F-f}\right)} = -21.468 + \underset{(0.197)}{0.254t} \qquad R^2 = 0.940$$

The results of these two models are shown graphically in Figure 7 below.

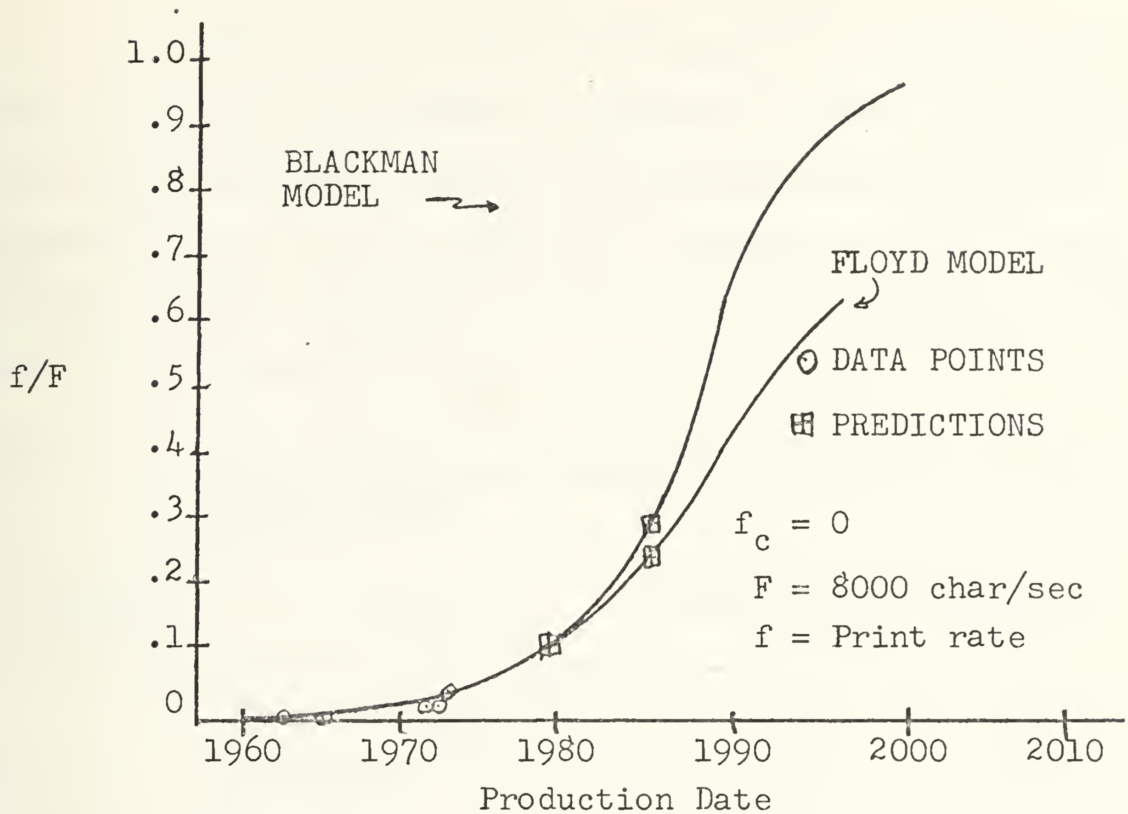


Figure 7. Hard Copy Terminals Print Rate Technology

From Figure 7, the following predictions can be made for the technology state-of-the-art level of print rates for hard copy terminals in Table III below.

TABLE III. HARD COPY TERMINAL PRINT RATE PREDICTIONS (TECHNOLOGY LEVEL)

	Blackman		Floyd	
	1980	1985	1980	1985
	720 cps	2320 cps	720 cps	1880 cps
Trend Probability	73.5%	56.9%	81.1%	70.5%

b. Technology Level for f = Transmission Speed

To determine where the level of the state-of-the-art is in hard copy terminal transmission speed, the data set was studied and only terminals with transmission speed advancements were used as inputs for termination of the model constants. The significant terminals for transmission speed are listed in Table IV below.

TABLE IV. LIST OF SIGNIFICANT HARD COPY TERMINALS (TRANSMISSION SPEED)

Terminal Number	Model	Transmission Speed	Production Date
1.	Teletype Model 33	110	1962.00
3.	Data Acess System DCT 500	300	1965.00
28.	Univac DCT 1000	4800	1971.25
62.	Centronics 308	9600	1974.25

The characteristics of these four significant terminals were regressed to calculate the constants for the two models. The resulting equations are:

BLACKMAN:

$$\ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$$

$$\widehat{\ln\left(\frac{f}{F-f}\right)} = -33.180 + \underset{(0.0946)}{0.381}\, t \qquad R^2 = 0.991$$

FLOYD:

$$\left(\frac{F}{F-f}\right) + \ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$$

$$\widehat{\left(\frac{F}{F-f}\right)} + \widehat{\ln\left(\frac{f}{F-f}\right)} = -32.220 + \underset{(0.0998)}{0.382}\, t \qquad R^2 = 0.990$$

The results of these two models are shown graphically in Figure 8 below.

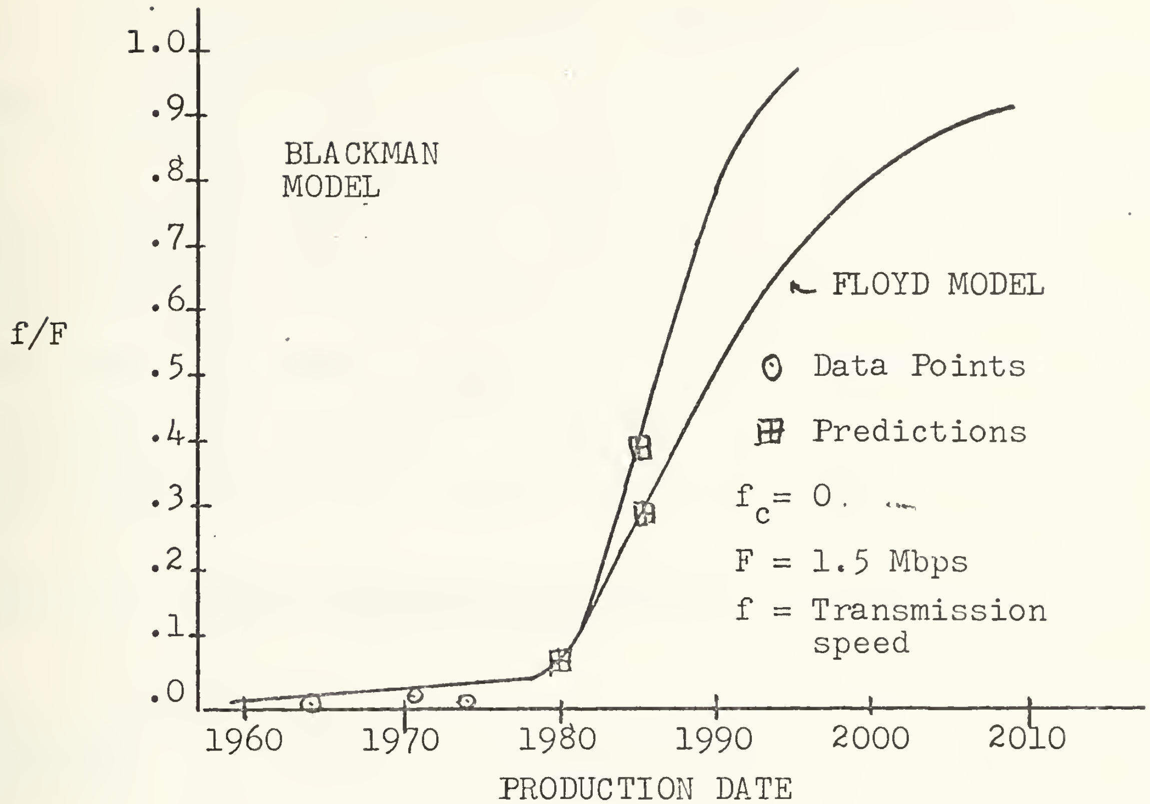


Figure 8. Hard Copy Terminals Transmission Speed Technology Level.

From Figure 8 the following predictions can be made for the technology state-of-the-art level of transmission speeds for hard copy (TTY) terminals in Table V below.

TABLE V. HARD COPY TERMINAL TRANSMISSION SPEED PREDICTIONS (TECHNOLOGY LEVEL)

	BLACKMAN		FLOYD	
	1980	1985	1980	1985
	90,000 bps	495,000 bps	90,000 bps	390,000 bps
Trend Probability	80.5%	53.6%	95.1%	78.8%

c. Technology Level for f = Print Rate/Purchase Price (Ave)

To determine where the level of the state-of-the-art is in hard copy terminal print rate / purchase price (ave), the data set was studied and only terminals with advancements were used as inputs for determination of the model constants. The significant terminals for print rate / purchase price (ave) are listed in Table VI below.

TABLE VI. LIST OF SIGNIFICANT HARD COPY TERMINALS (PRINT RATE / PURCHASE PRICE (AVE))

Terminal Number	Model	Print Rate / Purchase Price (Ave)	Production Date
1.	Teletype Model 33	0.0121	1962.00
12.	Carterfone 300	0.0179	1970.00
16.	Texas Instruments 721/731	0.0214	1971.25
34.	Printer Technology Printec 100	0.093	1971.75
58.	Scope Data Series	0.124	1973.50

The characteristics of these five significant terminals were regressed to calculate the constants for the two models. The resulting equations are:

BLACKMAN: $\ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$

$$\widehat{\ln\left(\frac{f}{F-f}\right)} = -15.919 + \underset{(0.483)}{0.192}\,t \qquad R^2 = 0.547$$

FLOYD: $\left(\frac{F}{F-f}\right) + \ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$

$$\widehat{\left(\frac{F}{F-f}\right)} + \widehat{\ln\left(\frac{f}{F-f}\right)} = -16.187 + \underset{(0.487)}{0.212}\,t \qquad R^2 = 0.538$$

The results of these two models are shown graphically in Figure 9 below.

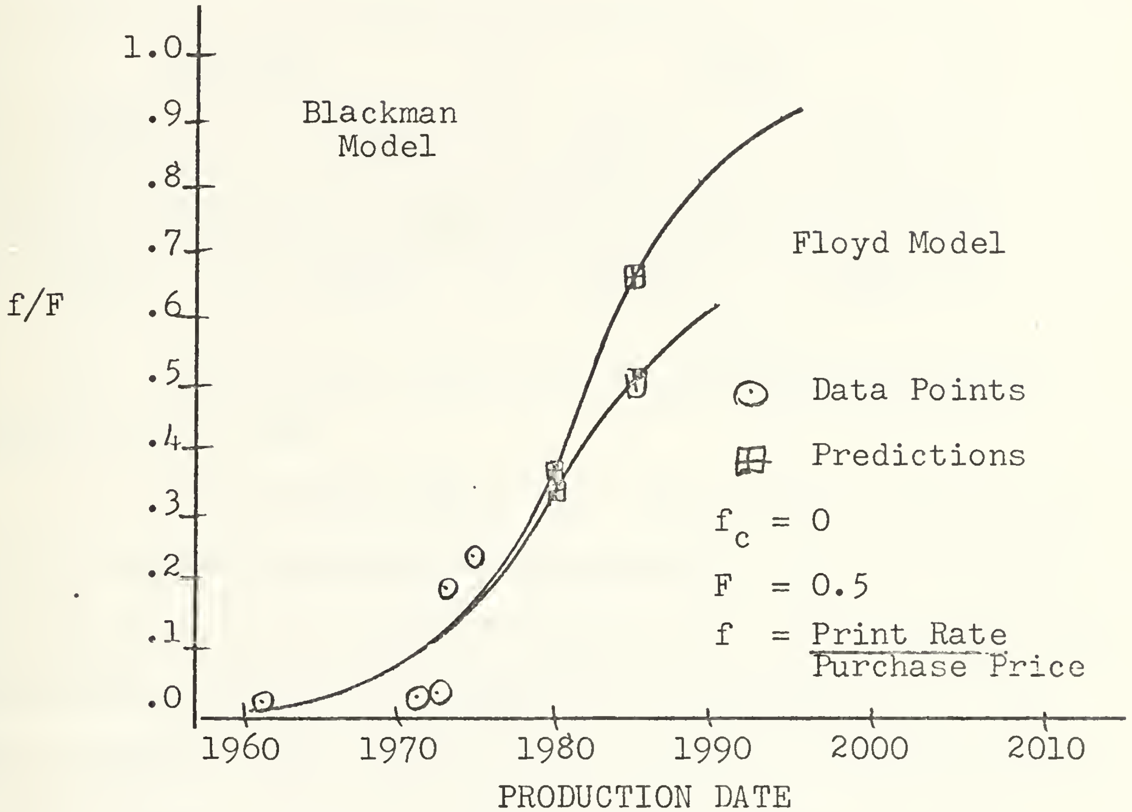


Figure 9. Hard Copy Terminals Print Rate / Purchase Price Technology Level.

From Figure 9, the following predictions can be made for the technology state-of-the-art level of print rate / purchase price (ave) for hard copy terminals in Table VII below.

TABLE VII. HARD COPY TERMINAL PRINT RATE / PURCHASE PRICE (AVE) PREDICTIONS (TECHNOLOGY LEVEL)

	BLACKMAN		FLOYD	
	1980	1985	1980	1985
Trend	0.185 CPS/$	0.2975 CPS/$	0.170 CPS/$	0.240 CPS/$
Probability	82.4%	69.5%	84.6%	75.5%

d. Technology Level for f = Transmission Speed / Purchase Price (Ave)

To determine where the level of the state-of-the-art is, in hard copy terminal transmission speed / purchase price (ave), the data set was studied and only terminals with advancements were used as inputs for determination of the model constants. The significant terminals for transmission speed / purchase price (ave) are listed in Table VII below.

TABLE VIII. LIST OF SIGNIFICANT HARD COPY TERMINALS (TRANS SPEED / PURCHASE PRICE (AVE))

Terminal Number	Model	Trans Speed / Purchase Price (Ave)	Production Date
1.	Teletype Model 33	0.133	1962.00
12.	Carterfone 300	0.179	1970.00
25.	Extel AE Series	0.214	1971.25
28.	UNIVAC DCT 1000	0.266	1971.25
34.	Printer Technology Printec 100	4.444	1971.75

The characteristics of these five significant terminals were regressed to calculate the constants for the two models. The resulting equations are:

BLACKMAN: $\ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$

$$\widehat{\ln\left(\frac{f}{F-f}\right)} = -17.393 + \underset{(0.5616)}{0.170}\,t \qquad R^2 = 0.232$$

FLOYD: $\left(\frac{F}{F-f}\right) + \ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$

$$\widehat{\left(\frac{F}{F-f}\right)} + \widehat{\ln\left(\frac{f}{F-f}\right)} = -16.503 + \underset{(0.5618)}{0.172}\,t \qquad R^2 = 0.230$$

The results of these two equations are shown graphically in Figure 10 below.

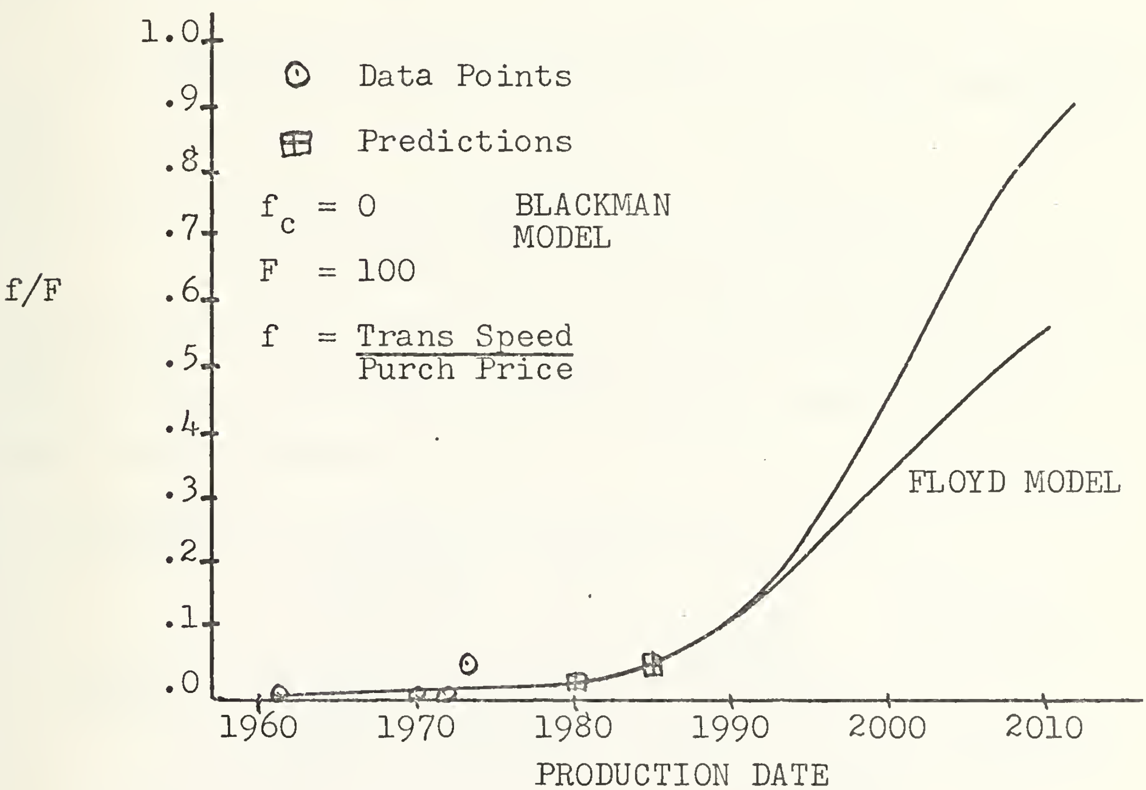


Figure 10. Hard Copy Terminals Transmission Speed / Purchase Price Technology Level.

From Figure 10, the following predictions can be made for the technology state-of-the-art level of transmission

speed / purchase price (ave) for hard copy terminals in Table IX below.

TABLE IX. HARD COPY TERMINAL TRANSMISSION SPEED / PURCHASE PRICE PREDICTIONS (TECHNOLOGY LEVEL)

	BLACKMAN		FLOYD	
	1980	1985	1980	1985
	1.5 bps/$	5 bps/$	1.5 bps/$	5 bps/$
Trend Probability	.996	.992	.996	.992

3. <u>Utilization Level Calculations for Hard Copy Terminals</u>

a. Utilization Level for f = Print Rate

To determine the utilization level and to fit the models to this level, data from all 67 terminals in the data set was regressed to determine the model constants. The resulting equations are:

<u>BLACKMAN</u>:

$$\ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$$

$$\widehat{\ln\left(\frac{f}{F-f}\right)} = -13.810 + \underset{(0.1227)}{0.114}\, t \qquad R^2 = 0.146$$

<u>FLOYD</u>:

$$\left(\frac{F}{F-f}\right) + \ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$$

$$\widehat{\left(\frac{F}{F-f}\right)} + \widehat{\ln\left(\frac{f}{F-f}\right)} = -12.850 + \underset{(0.1226)}{0.115}\, t \qquad R^2 = 0.147$$

The results of these equations are shown graphically in Figure 11 below.

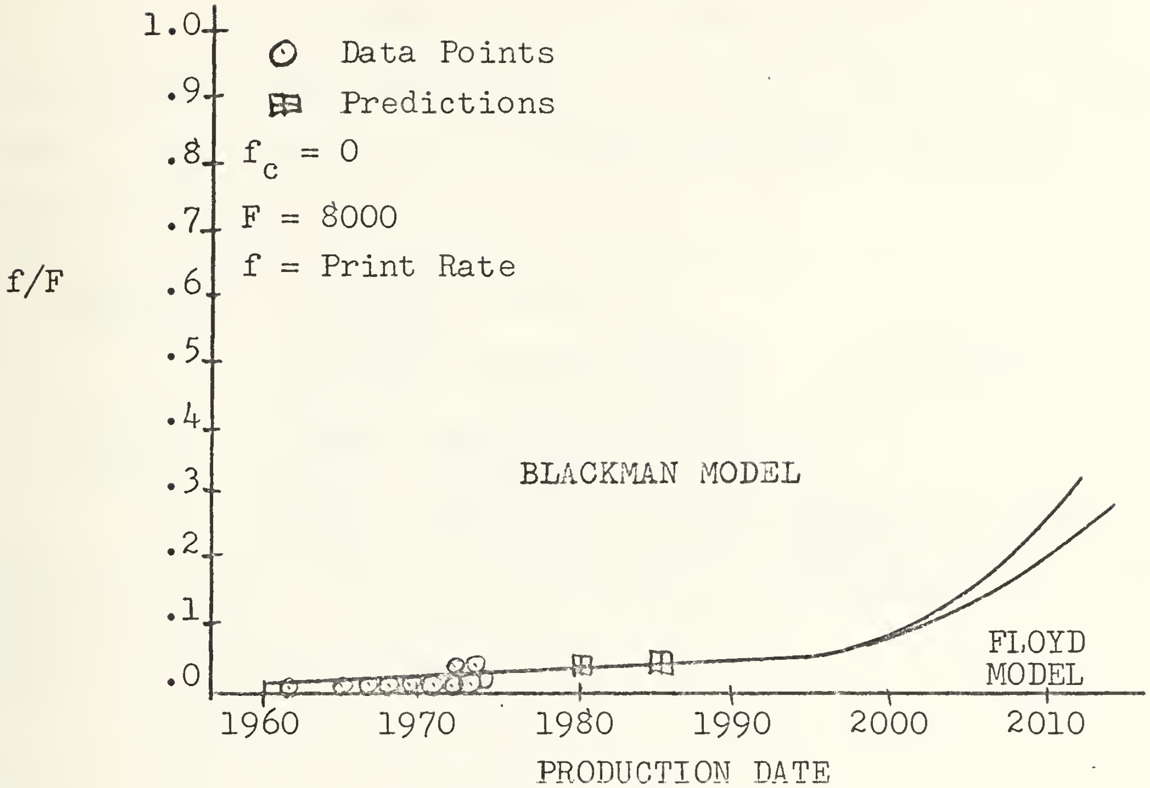


Figure 11. Hard Copy Terminals Print Rate Utilization Level.

From Figure 11 the following predictions can be made for the utilization level of print rate for hard copy terminals in Table X below.

TABLE X. HARD COPY TERMINAL PRINT RATE PREDICTIONS (UTILIZATION LEVEL)

	BLACKMAN		FLOYD	
	1980	1985	1980	1985
Trend	240 cps	320 cps	240 cps	320 cps
Probability	94.4%	91.0%	94.4%	91.0%

b. Utilization Level for f = Transmission Speed

To determine the utilization level and to fit the models to this level, data from all 67 terminals in the data set was regressed to determine the model constants. The resulting equations are:

BLACKMAN: $\ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$

$$\widehat{\ln\left(\frac{f}{F-f}\right)} = -21.360 + \underset{(0.1215)}{0.1910t} \qquad R^2 = 0.201$$

FLOYD: $\left(\frac{F}{F-f}\right) + \ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$

$$\widehat{\left(\frac{F}{F-f}\right)} + \widehat{\ln\left(\frac{f}{F-f}\right)} = -20.370 + \underset{(0.1215)}{0.1911t} \qquad R^2 = 0.201$$

The results of these two equations are shown graphically in Figure 12 below.

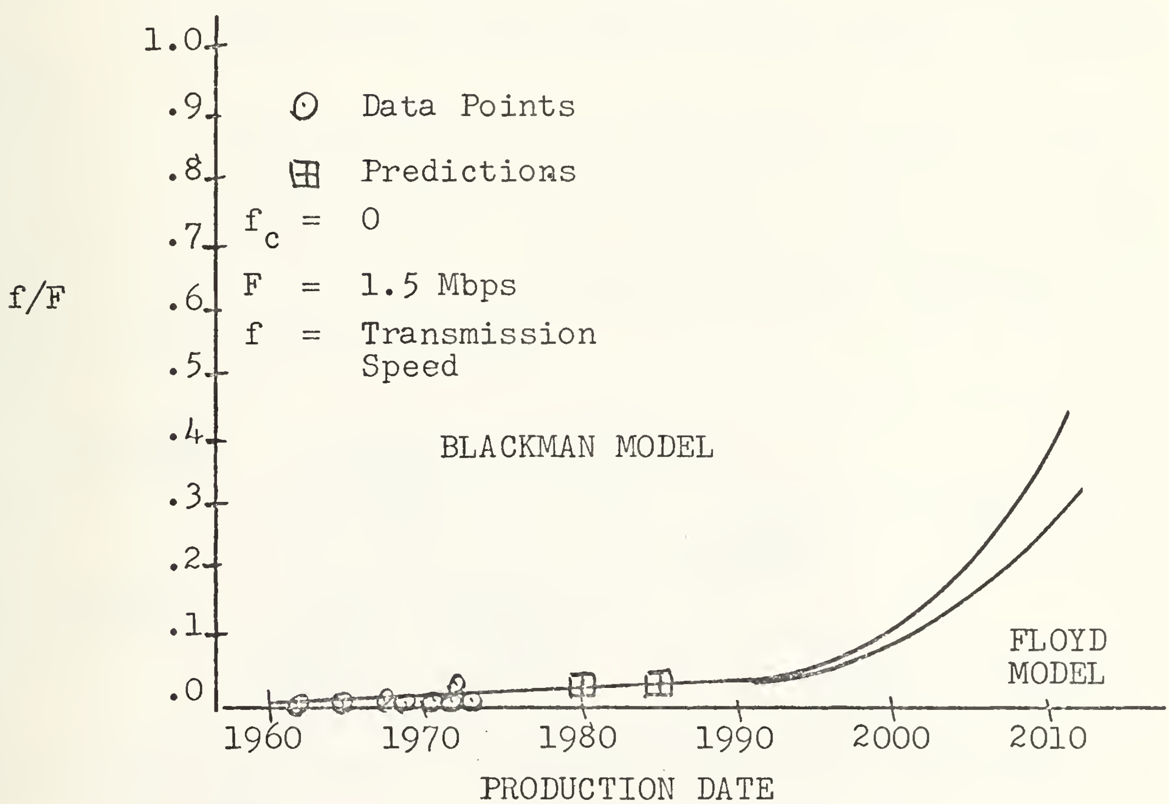


Figure 12. Hard Copy Terminals Transmission Speed Utilization Level.

From Figure 12, the following predictions can be made for the utilization level of transmission speed for hard copy terminals in Table XI below.

TABLE XI. HARD COPY TERMINAL TRANSMISSION SPEED PREDICTIONS (UTILIZATION LEVEL)

	BLACKMAN		FLOYD	
	1980	1985	1980	1985
Trend	1,600 bps	4,800 bps	1,600 bps	4,800 bps
Probability	99.4%	97.4%	99.4%	97.4%

c. Utilization Level for f = Print Rate / Purchase Price

To determine the utilization level and to fit the models to this level, data from all 67 terminals in the data set was regressed to determine the model constants. The resulting equations are:

BLACKMAN: $\ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$

$$\widehat{\ln\left(\frac{f}{F-f}\right)} = -10.378 + \underset{(0.124)}{0.0983}\, t \qquad R^2 = 0.059$$

FLOYD: $\left(\frac{F}{F-f}\right) + \ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$

$$\widehat{\left(\frac{F}{F-f}\right)} + \widehat{\ln\left(\frac{f}{F-f}\right)} = -9.639 + \underset{(0.124)}{0.0984}\, t \qquad R^2 = 0.059$$

The results of these two equations are shown graphically in Figure 13 below.

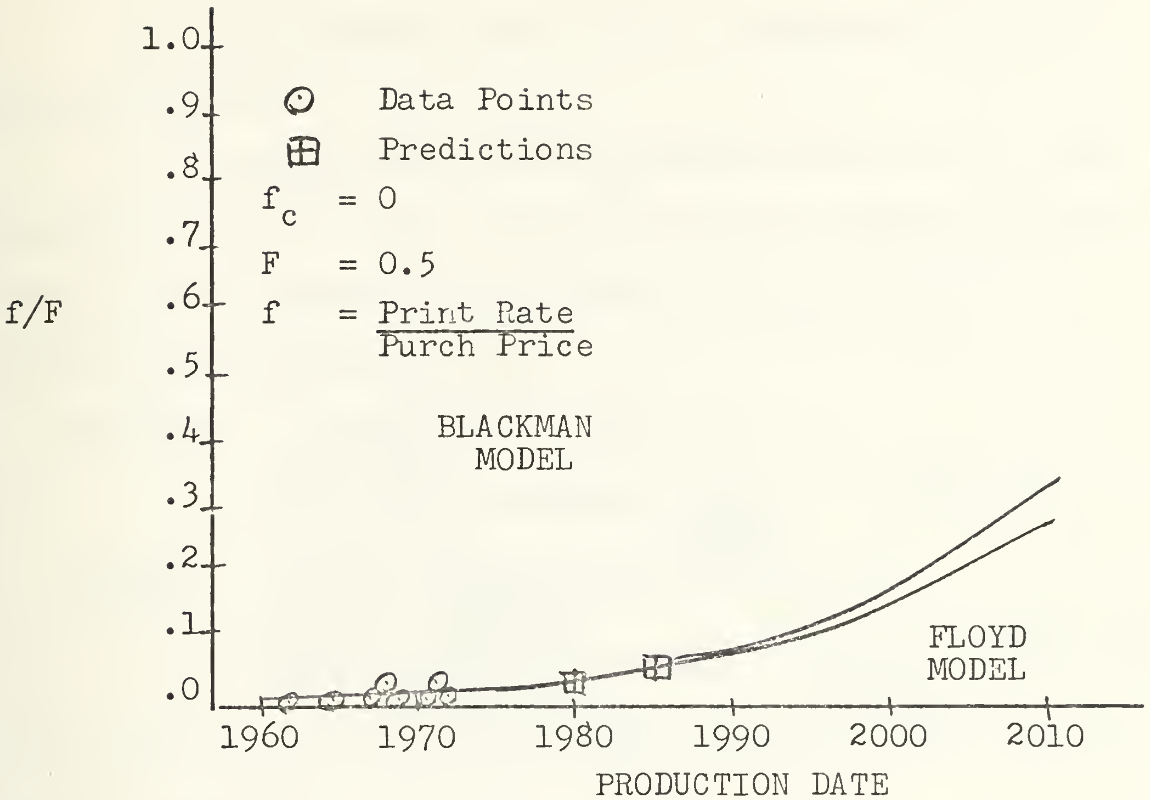


Figure 13. Hard Copy Terminals Print Rate / Purchase Price Utilization Level.

From Figure 13, the following predictions can be made for the utilization level of print rate / purchase price (ave) for hard copy terminals in Table XII below.

TABLE XII. HARD COPY TERMINAL PRINT RATE / PURCHASE PRICE (AVE) PREDICTIONS (UTILIZATION LEVEL)

	BLACKMAN		FLOYD	
	1980	1985	1980	1985
Trend	0.02 CPS/$	0.03 CPS/$	0.02 CPS/$	0.03 CPS/$
Probability	98.6%	97.7%	98.6%	97.7%

d. Utilization Level for f = Transmission Speed / Purchase Price

To determine the utilization level and to fit the models to this level, data from all 67 terminals in the data set was regressed to determine the model constants. The resulting equations are:

BLACKMAN: $\ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$

$$\widehat{\ln\left(\frac{f}{F-f}\right)} = -18.292 + \underset{(0.123)}{0.161\,t} \qquad R^2 = 0.153$$

FLOYD: $\left(\frac{F}{F-f}\right) + \ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$

$$\widehat{\left(\frac{F}{F-f}\right)} + \widehat{\ln\left(\frac{f}{F-f}\right)} = -17.323 + \underset{(0.123)}{0.162\,t} \qquad R^2 = 0.152$$

The results of these two equations are shown graphically in Figure 14 below.

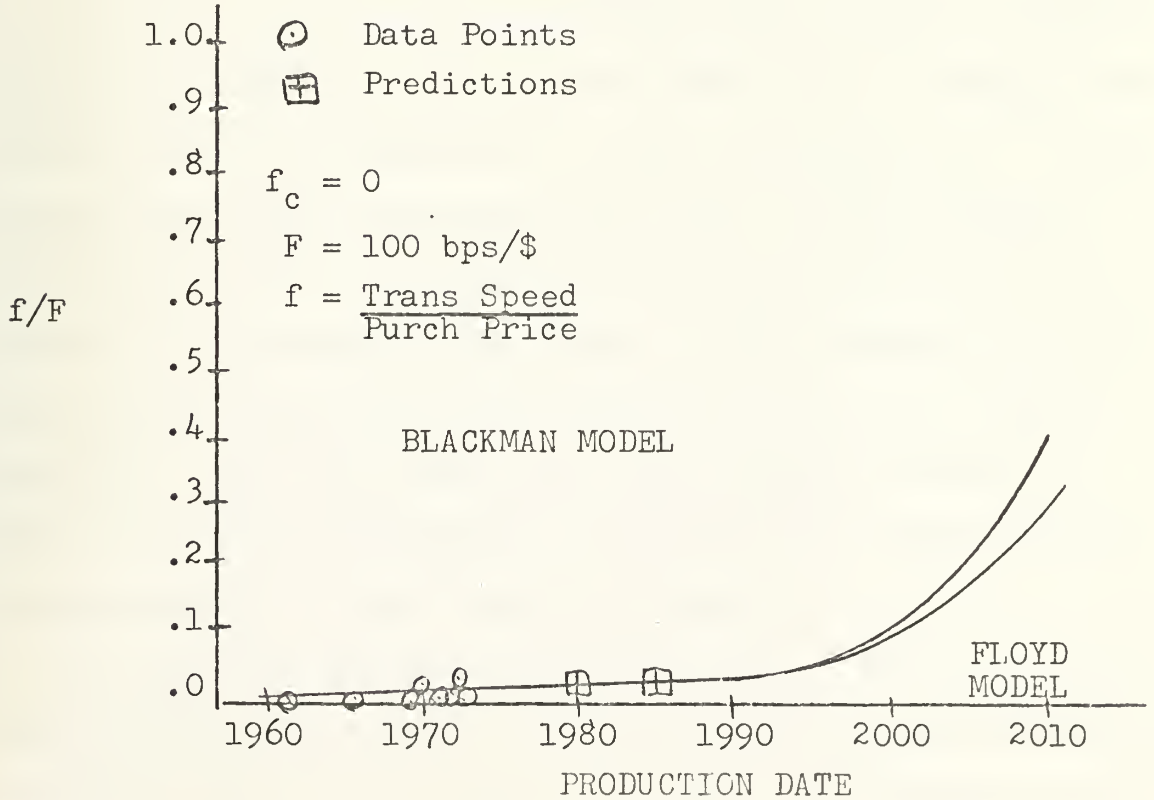


Figure 14. Hard Copy Terminals Transmission Speed / Purchase Price Utilization Level

From Figure 14, the following predictions can be made for the utilization level of transmission speed / purchase price (ave) for hard copy terminals in Table XIII below.

TABLE XIII. HARD COPY TERMINAL TRANSMISSION SPEED / PURCHASE PRICE (AVE) (UTILIZATION LEVEL)

	BLACKMAN		FLOYD	
	1980	1985	1980	1985
Trend	1.0 bps/$	1.5 bps/$	1.0 bps/$	1.5 bps/$
Probability	.997	.992	.997	.992

C. VIDEO DISPLAY TERMINALS

The first commercially available video display terminal appeared in 1965 and, since then, this type of terminal has become almost as commonplace as the teletypewriter.[38] The capabilities that have helped the video display terminal reach such a level of acceptance are the figures-of-merit needed to make future predictions. Before determining these parameters, a definition is needed for the video display terminal. For this study, the video display terminal is defined as any communication terminal with a video display, a keyboard and a communication interface.

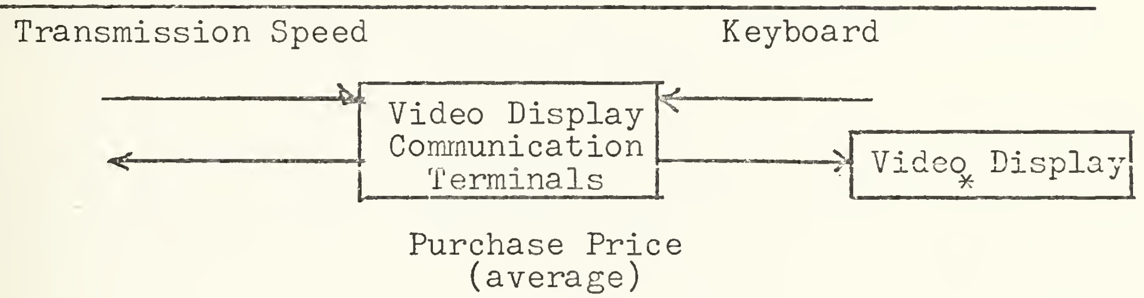
In applying the two mathematical models for trend extrapolation to video display terminals, quantifiable performance parameters must be identified for use in developing figures-

of-merit. Referring back to the three key areas (visual display, communication interface and keyboard) of the video display terminal definition, transmission speed can be used to measure communication interface efficiency and the maximum number of display characters can be used to measure video display ability. Keyboard efficiency, though, is a function of the operator and for this analysis an average operator will be assumed. Also, the economic parameter of purchase price will be used as a third parameter to determine cost trends.

The transmission speed of a video display terminal is specified in bits per second and is usually limited by the compatability requirements of the communication system it is a part of and by the communication lines being used. The number of display positions is specified by characters per display and is a function of the number of lines in a display and the number of characters per line. Progress in this area, though, is difficult to measure because at present the need for large displays is minimal. In fact, the terminal in the data set with the largest number of display positions (6000 char/display) appeared in 1969 and since then the majority of terminals have been around 2000 characters per display. This is understandable when one notes that the main function of the display is to show segments of data when needed and not to show all the data. For this reason large displays are not needed and for this study 6000

characters per display will be used as the maximum to calculate the upper limit for f equal to maximum display positions per dollar of purchase price and no attempt will be made to predict higher display position capacities.

In applying the models to video display communication terminals, the terminals will be looked at as a simple input/output model (See Figure 15 below). From this model three parameters can be defined to be used as figures-of-merit and they are listed below the diagram.



Figures-of-merit

1. Transmission speed
2. Maximum Video Display Positions / Purchase Price (ave)
3. Transmission Speed / Purchase Price (ave)

* Maximum Video Display = 6000 Char/Display

Figure 15. Input/Output Model for Video Display Terminals.

Using the definition of video display terminals, a list of terminals was compiled from DATAPRO 70, THE EDP BUYERS BIBLE.[39] Table XIV below lists all the video display terminals compiled and gives their important parameters.

Only terminals with maximum number of video display positions, transmission speed, purchase price and production date were considered.

TABLE XIV. OVERALL LIST OF VIDEO DISPLAY TERMINALS

MODEL	MAX DISPLAY POSITS	TRANS SPEED	PURCHASE PRICE			PROD DATE
			MAX	MIN	AVE	
1. Sanders Model 720	2000.	9600.	3277.	3177.	3227.	1966.00
2. IBM Model 2260	960.	2400.	2140.	1270.	1705.	1966.25
3. Datapoint Model 3000	1800.	2400.	3240.	2400.	2820.	1968.00
4. Sanders Model 620	2000.	2400.	13455.	5670.	9563.	1968.00
5. Information Displays ID110	6000.	9600.	66000.	66000.	66000.	1969.00
6. IBM Model 2265	960.	2400.	6330.	6330.	6330.	1969.25
7. GTE IS 7000	960.	2400.	4880.	4880.	4880.	1969.75
8. Incoterm SPD 10/20	1920.	9600.	5800.	5800.	5800.	1970.00
9. Hendrix EDS 5200	3072.	9600.	14900.	11900.	13400.	1970.00
10. Delta Data Model 5300	2160.	2400.	5600.	5000.	5300.	1970.00
11. Delta Data Model 5000	3072.	9600.	4500.	3000.	3750.	1970.00
12. Datapoint 3360	2048.	4800.	2900.	2900.	2900.	1970.00
13. Xerox BC 100	1600.	9600.	3500.	750.	2125.	1970.00
14. Datapoint 3300	1800.	2400.	2400.	2400.	2400.	1970.00
15. Bunker Ramo 2210	200.	4800.	760.	760.	760.	1970.00
16. Bunker Ramo 2212	480.	4800.	1345.	1345.	1345.	1970.00
17. Bunker Ramo 2206	1920.	4800.	1390.	1390.	1390.	1970.00
18. ADDS MRD 780	1920.	9600.	3695.	2550.	3123.	1970.25
19. ADDS Envoy 680	1920.	300.	4090.	3895.	3993.	1970.25
20. ADDS Consul 580	1920.	9600.	3710.	2990.	3350.	1970.25

21. Data 100 Model 73	1920.	1200.	3950.	3750.	3850.	1970.50
22. Datamedia 1500	1920.	1800.	1895.	1775.	1835.	1970.50
23. Courier 60	1920.	4800.	3050.	3050.	3050.	1970.50
24. Conrac Model 401	2000.	9600.	3300.	2600.	2950.	1970.50
25. ITT Model 3100	1920.	4800.	2500.	1200.	1850.	1970.75
26. Hazeltine 1000	1998.	9600.	2995.	2995.	2995.	1970.75
27. Four Phase Systems 70	1920.	9600.	1845.	1845.	1845.	1971.00
28. Computer Optics CO 75	3000.	4800.	2498.	2498.	2498.	1971.00
29. Lear Siegler 7700A	2000.	9600.	2895.	2895.	2895.	1971.25
30. Courier 265	1920.	4800.	4600.	4600.	4600.	1971.25
31. Courier 260	1920.	4800.	4250.	4250.	4250.	1971.25
32. Control Data 713	640.	300.	2315.	1995.	2155.	1971.25
33. Control Data 711	640.	4800.	4120.	3500.	3810.	1971.25
34. Int. Computer 7181	1600.	4800.	3395.	3395.	3395.	1971.50
35. Digital Equip. VT05	1440.	2400.	2795.	2795.	2795.	1971.75
36. Sanders Model 804	1920.	9600.	11115.	6055.	8585.	1971.75
37. Kustom MCT 10	256.	1300.	3200.	3200.	3200.	1972.00
38. Info Displays ID1	3000.	9600.	4000.	4000.	4000.	1972.00
39. Datamedia 1500	1920.	4800.	1555.	1375.	1465.	1972.00
40. Computek 200	2000.	19200.	6000.	3000.	4500.	1972.00
41. Ann Arbor 200 KSR	3200.	9600.	674.	390.	532.	1972.00
42. IBM 3275	1920.	4800.	9535.	6100.	7818.	1972.25
43. IBM 3277	1920.	4800.	7435.	4000.	5718.	1972.25
44. Hendrix EDS 5200	960.	9600.	18000.	12300.	15150.	1972.25

45. GTE IS 7100	1920.	55000.	55560.	37576.	46568.	1972.25
46. Hughes Acft. 1201	3230.	19200.	16000.	11500.	13750.	1972.50
47. Digital Equip. GT 40	2432.	9600.	15695.	13400.	14548.	1972.50
48. Megadata 1000	2160.	19000.	8000.	3500.	5750.	1972.75
49. ITT 3501	960.	2400.	2195.	2195.	2195.	1972.75
50. Hughes Acft. 1201	3230.	19200.	17800.	13300.	15550.	1972.75
51. Datamedia 2100A	1920.	9600.	2095.	2035.	2065.	1972.75
52. Courier 250	1920.	300000.	3650.	3650.	3650.	1972.75
53. Carmel I 211	512.	9600.	2200.	1850.	2025.	1972.75
54. Megadata MAC-NET	2160.	19000.	7500.	4000.	5750.	1973.00
55. Teletype Model 40	1920.	1200.	5610.	2995.	4303.	1973.00
56. Infoton Vistar	1920	9600.	2295.	2295.	2295.	1973.00
57. Bunker Ramo 2204	1920.	4800.	1440.	1440.	1440.	1973.00
58. Incoterm SPD 900	1920.	9600.	23400.	12400.	17900.	1973.25
59. Hazeltine 1000	960.	9600.	1750.	1750.	1750.	1973.25
60. Conrac 401	480.	9600.	1200.	925.	1063.	1973.25
61. Beehive SB 2	2000.	9600.	1795.	1795.	1795.	1973.25
62. Lear Siegler ADM 1	1920.	9600.	1600.	1600	1600.	1973.50
63. Four Phase Sys IV	1920.	9600.	1845.	1845.	1845.	1973.50
64. Digi Log 3300	1920.	9600.	2100.	1200.	1650.	1973.50
65. Datamedia 2500	1920.	9600.	2080.	2080.	2080.	1973.50
66. Courier 267	1920.	4800.	6500.	6500.	6500.	1973.50
67. Control Data 714	1280.	4800.	3900.	3300.	3600.	1973.50
68. Carmel D-301	512.	9600.	1950.	1950.	1950.	1973.50

69. Burroughs 800	1920.	9600.	5490.	4750.	5120.	1973.50
70. Beehive MB 2	2000.	9600.	1795.	1705.	1750.	1973.50
71. Beehive MB1	1920.	9600.	3800.	3300.	3550.	1973.50
72. ADDS 580	1920.	9600.	1785.	1795.	1790.	1973.50
73. Infoton GT	1920.	9600.	1595.	1595.	1595.	1973.75
74. IMLAC PDS 4	4000.	200000.	13900.	13900.	13900.	1973.75
75. IMLAC PDS 1G	1900.	200000.	7500.	7500.	7500.	1973.75
76. Honeywell 7700	1920.	4800.	5760	4860.	5310.	1973.75
77. Courier C270	1920.	535000.	279350.	68500.	173925.	1973.75
78. Ann Arbor III KSR	3200.	9600.	2665.	1640.	2153.	1973.75
79. Ann Arbor III KSR	3200.	9600.	2760.	2200.	2480.	1973.75
80. Carmel D 302	512.	9600.	2050	2050.	2050.	1974.00
81. Comp. Comm 40	3200.	9600.	5600.	2950.	4275.	1974.00
82. Comp Optics 77	1920.	9600.	6233.	6233.	6233.	1974.00
83. Courier C270	1920.	9600.	141500.	36000.	88750.	1974.00
84. Datapoint 1100	960.	9600.	8040	4670.	6355.	1974.00
85. GTE 7801	1920.	9600.	3050.	1850.	2450.	1974.00
86. GTE 7805	1920.	9600.	7100.	5700.	6400.	1974.00
87. Hewlett Packard 2615	2000.	9600.	2750	2750.	2750.	1974.00
88. Hewlett Packard 2616	2000.	9600.	4500.	4500.	4500.	1974.00
89. Jacquard 100	1920.	9600.	1300.	1300.	1300.	1974.00
90. NCR 101	1920.	9600.	2000.	2000.	2000.	1974.00
91. NCR 101	1920.	9600.	3000.	3000.	3000.	1974.00
92. NCR 301	1920.	9600.	3500.	3500.	3500.	1974.00

93. Olivetti 520	341.	4800.	14000.	6100.	10050.	1974.00
94. Beehive MB 4	2000.	9600.	2195.	1995.	2095.	1974.25
95. Beehive SB 4	2000.	9600.	3295.	3295.	3295.	1974.25
96. Courier C275	1920.	9600.	5050.	4700.	4875.	1974.25
97. Lear Siegler ADM 2	1920.	9600.	2500.	2500.	2500.	1974.25
98. Olivetti 520	1920.	4800.	8130.	3620.	5875.	1974.25
99. Courier C275 MS	1920.	9600.	24300.	22750.	23525.	1974.50

1. Science Level for Video Display Terminals

For the three figures-of-merit to be analyzed, only one parameter, transmission speed, has a science level. The level for transmission speed was set at 1.5 Mbps for the hard copy terminal and this limit also applies to the video display terminal. The logic in setting this limit is the same as discussed in the hard copy terminal section and will not be repeated here.

2. Technology Level for Video Display Terminals

a. Technology Level for f = Transmission Speed

To determine where the level of the state-of-the-art is in video display terminal speed, the data set was studied and only terminals with transmission speed advancements were used as inputs for the determination of the model constants. The significant terminals for print rate are listed in Table XV below.

TABLE XV. LIST OF SIGNIFICANT VIDEO DISPLAY TERMINALS. (TRANSMISSION SPEED)

Terminal Number	Model	Transmission Speed	Production Date
1.	Sanders Model 720	9600	1966.00
40.	Computek 200	19200	1972.00
45.	GTE IS 7100	55000	1972.25
52.	Courier 250	300000	1972.25
77.	Courier C270	535000	1973.75

The characteristics of these five significant terminals were regressed to calculate the constants for the two models. The resulting equations are:

BLACKMAN: $\ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$

$$\widehat{\ln\left(\frac{f}{F-f}\right)} = -36.430 + \underset{(0.467)}{0.475}\,t \qquad R^2 = 0.587$$

FLOYD: $\left(\frac{F}{F-f}\right) + \ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$

$$\widehat{\left(\frac{F}{F-f}\right)} + \widehat{\ln\left(\frac{f}{F-f}\right)} = -38.391 + \underset{(0.487)}{0.520}\,t \qquad R^2 = 0.567$$

The results of these two models are shown graphically in Figure 16 below.

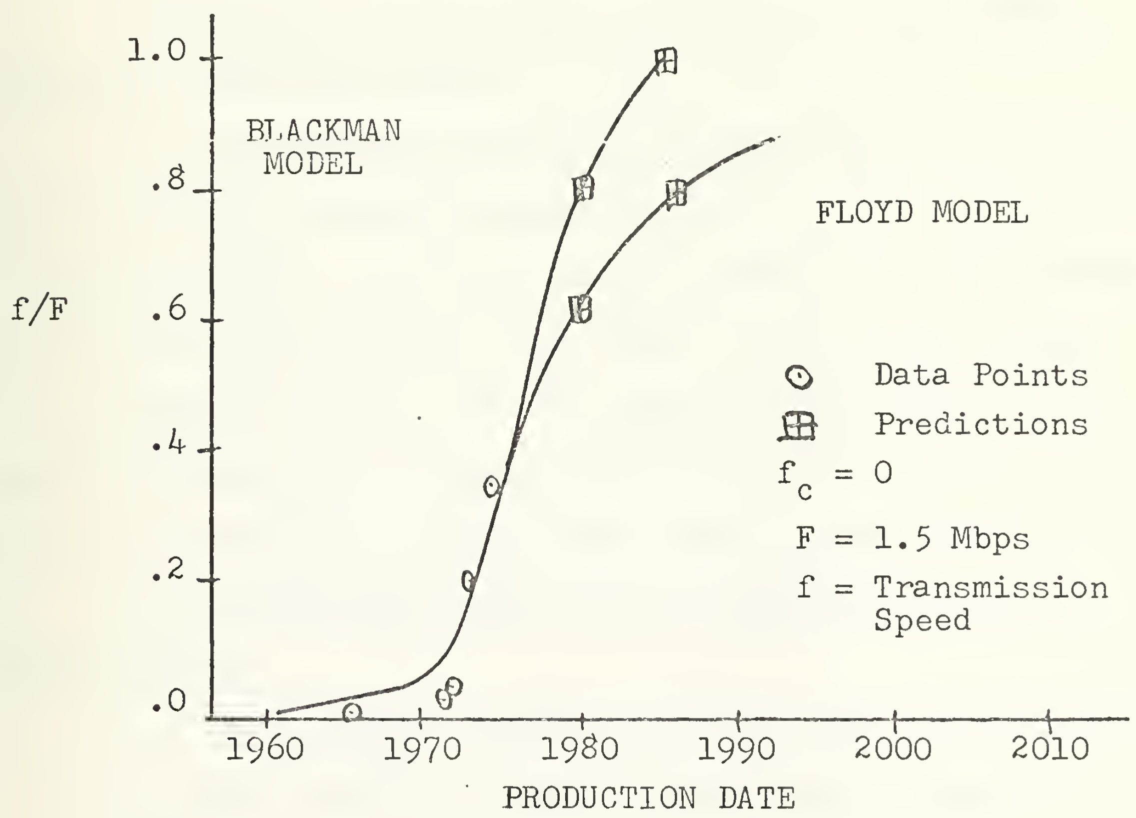


Figure 16. Video Display Terminals Transmission Speed Technology Level.

From Figure 16, the following predictions can be made for the technology state-of-the-art level of

transmission speeds for video display terminals in Table XVI below.

TABLE XVI. VIDEO DISPLAY TERMINAL TRANSMISSION SPEED PREDICTIONS (TECHNOLOGY LEVEL)

	BLACKMAN		FLOYD	
	1980	1985	1980	1985
Trend	1.23 Mbps	1.47 Mbps	0.93 Mbps	1.17 Mbps
Probability	53.25%	51.2%	71.9%	58.2%

b. Technology Level for f = Maximum Video Display Positions / Purchase Price

To determine where the level of the state-of-the-art is in video display terminal display positions per dollar of purchase price, the data set was studied and only terminals with advancing values were used. In this case though, it is noted that since 1970 the upper level has stayed constant at around 1.35 display positions per dollar of purchase price and therefore no prediction will be attempted.

c. Technology Level for f = Transmission Speed / Purchase Price

To determine where the level of the state-of-the-art is in video display terminal transmission speed / purchase price, the data set was studied and only terminals with advancing values were used as inputs for the determination of the model constants. The significant terminals for

transmission speed / purchase price are listed in Table XVII below.

TABLE XVII. LIST OF SIGNIFICANT VIDEO DISPLAY TERMINALS. (TRANS SPEED / PURCH PRICE)

Terminal Number	Model	Trans Speed / Purchase Price	Production Date
1.	Sanders Model 720	2.9749	1966.00
15.	Bunker Ramo 2210	6.3158	1970.00
41.	Ann Arbor 200 KSR	18.0551	1972.00
52.	Courier 250	82.1918	1972.75

The characteristics of these four significant terminals were regressed to calculate the constants for the two models. The resulting equations are:

BLACKMAN: $$\ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$$

$$\widehat{\ln\left(\frac{f}{F-f}\right)} = -34.733 + \underset{(0.453)}{0.456}\,t \qquad R^2 = 0.768$$

FLOYD: $$\left(\frac{F}{F-f}\right) + \ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$$

$$\widehat{\left(\frac{F}{F-f}\right)} + \widehat{\ln\left(\frac{f}{F-f}\right)} = -36.218 + \underset{(0.476)}{0.494}\,t \qquad R^2 = 0.739$$

The results of these two models are shown graphically in Figure 17 below.

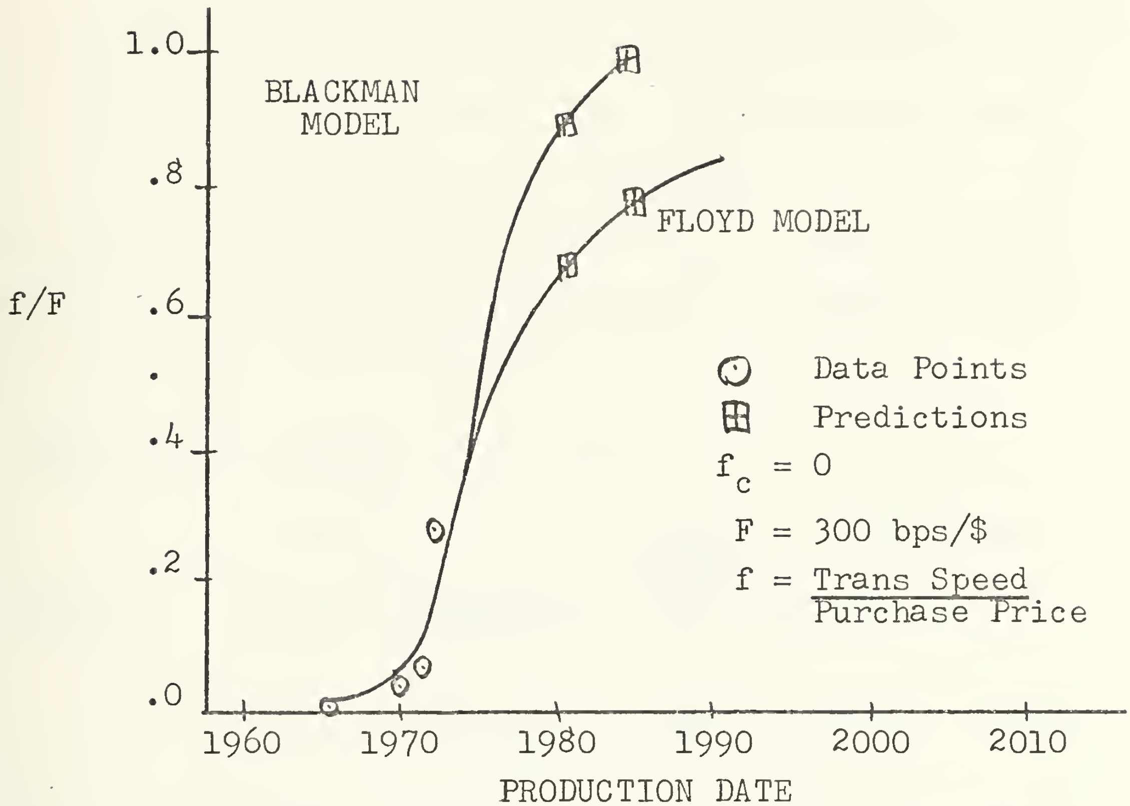


Figure 17. Video Display Terminals Transmission Speed / Purchase Price Technology Level.

From Figure 17, the following predictions can be made for the technology state-of-the-art level of transmission speeds / purchase price for video display terminals in Table XVIII below.

TABLE XVIII. VIDEO DISPLAY TERMINAL TRANS SPEED / PURCHASE PRICE PREDICTIONS (TECHNOLOGY LEVEL)

	BLACKMAN		FLOYD	
	1980	1985	1980	1985
Trend	258 bps/$	294 bps/$	189 bps/$	231 bps/$
Probability	55%	50%	70.7%	61.6%

3. <u>Utilization Level for Video Display Terminals</u>

a. Utilization Level for f = Transmission Speed

To determine the utilization level and to fit the models to this level, data from all 99 video display terminals in the data set was regressed to determine the model constants. The resulting equations are:

<u>BLACKMAN:</u>

$$\ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$$

$$\ln\left(\frac{f}{F-f}\right) = -19.670 + \underset{(0.1006)}{0.221\,t} \qquad R^2 = 0.135$$

<u>FLOYD:</u>

$$\left(\frac{F}{F-f}\right) + \ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$$

$$\left(\frac{F}{F-f}\right) + \ln\left(\frac{f}{F-f}\right) = -18.986 + \underset{(0.1007)}{0.226\,t} \qquad R^2 = 0.30$$

The results of these two models are shown graphically in Figure 18 below.

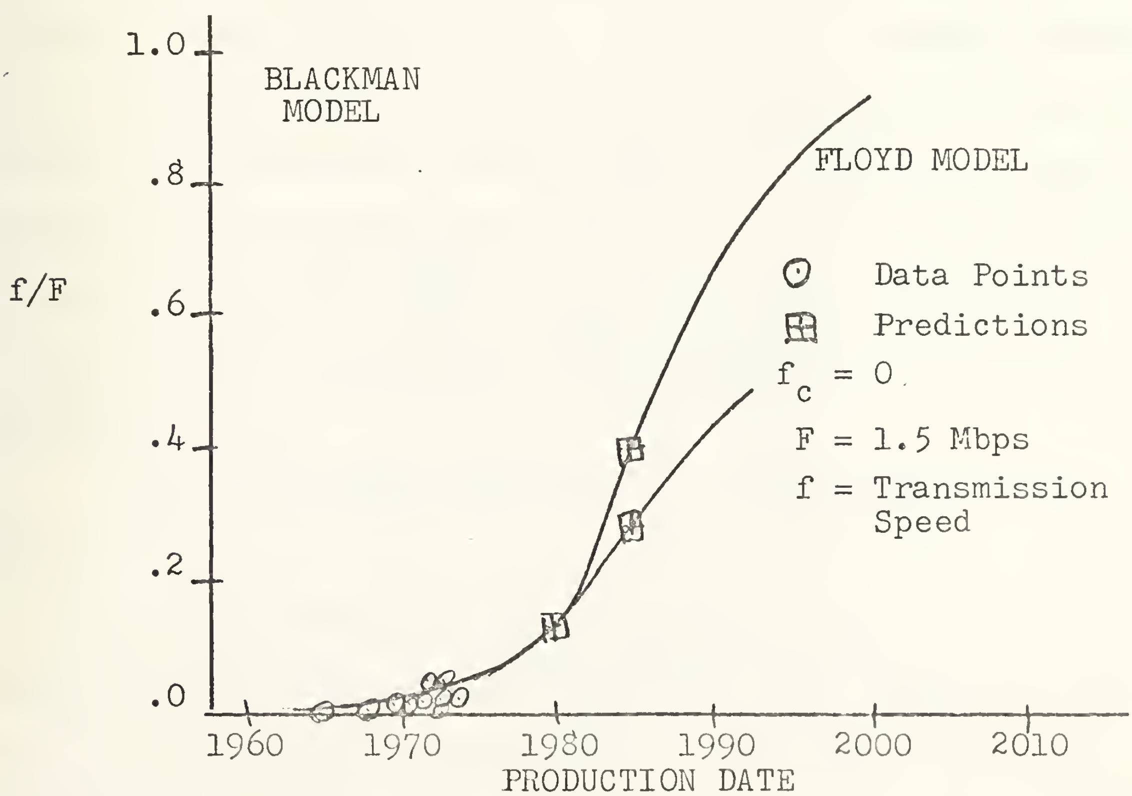


Figure 18. Video Display Terminals Transmission Speed Utilization Level.

From Figure 18, the following predictions can be made for the utilization level of transmission speed for video display terminals in Table XIX below.

TABLE XIX. VIDEO DISPLAY TERMINAL TRANSMISSION SPEED PREDICTIONS (UTILIZATION LEVEL)

	BLACKMAN		FLOYD	
	1980	1985	1980	1985
Trend	0.195 Mbps	0.405 Mbps	0.195 Mbps	0.33 Mbps
Probability	96.9%	96.0%	96.9%	96.3%

b. Utilization Level for f = Maximum Video Display Positions / Purchase Price

To determine the utilization level and to fit the models to this level, data from all 99 video display terminals in the data set was regressed to determine the model constants. The regression showed that the trend had a slightly negative slope but since the technology level was essentially constant, it is felt that this trend is not significant enough to make a prediction, and no prediction will be attempted.

c. Utilization Level for f = Trans Speed / Purch Price

To determine the utilization level and to fit the models to this level, data from all 99 video display terminals in the data set was regressed to determine the model constants. The resulting equations are:

BLACKMAN: $\ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$

$$\widehat{\ln\left(\frac{f}{F-f}\right)} = -16.660 + \underset{(0.101)}{0.182t} \qquad R^2 = 0.082$$

FLOYD: $\left(\frac{F}{F-f}\right) + \ln\left(\frac{f}{F-f}\right) = C_1 + C_2 t + e$

$$\widehat{\left(\frac{F}{F-f}\right)} + \widehat{\ln\left(\frac{f}{F-f}\right)} = -15.802 + \underset{(0.101)}{0.185t} \qquad R^2 = 0.081$$

The results of these two models are shown graphically in Figure 19 below.

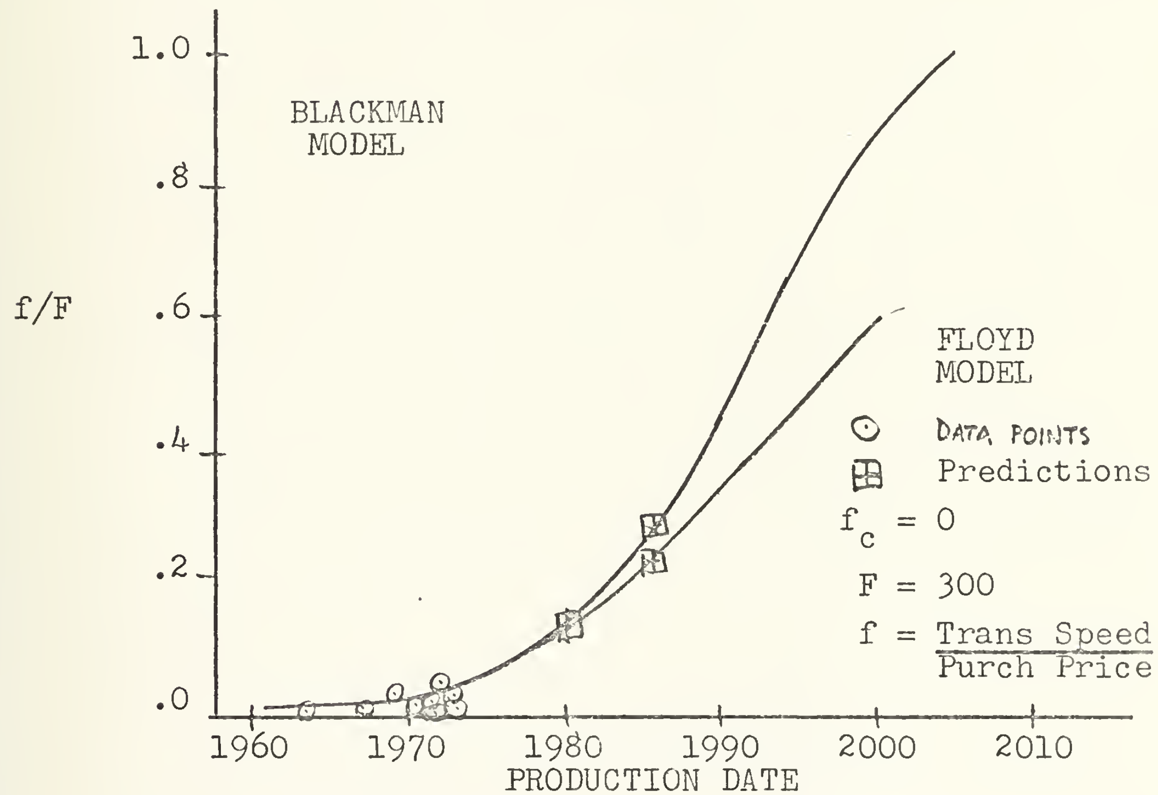


Figure 19. Video Display Terminal Transmission Speed / Purchase Price Utilization Level.

From Figure 19, the following predictions can be made for the utilization level of transmission speed / purchase price for video display terminals in Table XX below.

TABLE XX. VIDEO DISPLAY TERMINAL TRANS SPEED / PURCH PRICE PREDICTIONS (UTILIZATION LEVEL)

	BLACKMAN		FLOYD	
	1980	1985	1980	1985
Trend	33 bps/$	75 bps/$	33 bps/$	63 bps/$
Probability	96.4%	94.4%	96.4%	94.6%

III. CONCLUSION

Having selected performance parameters, gathered data on these parameters, fitted the Floyd and Blackman models to the data, and made the predictions from the trend extrapolation, there is only one thing left to do, interpret the results. In interpreting the predictions, one should remember one important idea. That is "the forecaster must have the courage of his convictions. He has taken historical data, determined that there is some regularity in the past pattern of innovation and projected this regularity into the future."[40] He should stand up and report the results as they are and not the way he thinks they should be. With this thought in mind, the predictions of this study are presented in Table XXI. Also, the predictions will be discussed by looking at four major areas: hard copy terminal print rate and transmission speed, and video display terminal display positions and transmission speed.

First, in the area of hard copy terminal print rate, the predictions show a sharp increase, up to approximately 2000 characters per second (cps) by 1985 and an even more rapid increase in the period between 1985 and the year 2000. During this period the Blackman model predicts print rates of about 7500 cps while the Floyd model predicts print rates around 5500 cps. These rates are at the state-of-the-art level and print rates in the widespread acceptance level will lag behind. The print rates of widely accepted terminals

TABLE XXI. OVERALL TREND PREDICTIONS

Terminal Type	Level	Figures of Merit	Model Used	Predictions 1980	Predictions 1985
HARDCOPY	T	Print Rate	B	720 cps	2320 cps
			F	720 cps	1880 cps
	T	Transmission Speed	B	0.09 Mbps	0.495 Mbps
			F	0.09 Mbps	0.395 Mbps
	T	Print Rate / Purchase Price	B	0.185 cps/$	0.297 cps/$
			F	0.170 cps/$	0.240 cps/$
	T	Transmission Speed / Purchase Price	B	1.5 bps/$	5.0 bps/$
			F	1.5 bps/$	5.0 bps/$
	U	Print Rate	B	240 cps	320 cps
			F	240 cps	320 cps
	U	Transmission Speed	B	1,600 bps	4,800 bps
			F	1,600 bps	4,800 bps
	U	Print Rate / Purchase Price	B	0.02 cps/$	0.03 cps/$
			F	0.02 cps/$	0.03 cps/$
	U	Transmission Speed / Purchase Price	B	1.0 bps/$	1.5 bps/$
			F	1.0 bps/$	1.5 bps/$
VIDEO DISPLAY	T	Transmission Speed	B	1.23 Mbps	1.47 Mbps
			F	0.93 Mbps	1.17 Mbps
	T	Transmission Speed / Purchase Price	B	258 bps/$	294 bps/$
			F	189 bps/$	231 bps/$
	U	Transmission Speed	B	0.195 Mbps	0.405 Mbps
			F	0.195 Mbps	0.33 Mbps
	U	Transmission Speed / Purchase Price	B	33 bps/$	75 bps/$
			F	33 bps/$	63 bps/$

B = BLACKMAN MODEL, F = FLOYD MODEL, T = TECHNOLOGY LEVEL, U = UTILIZATION LEVEL

will increase to around 240 cps by 1985. This utilization level for print rate will continue to moderately increase until around the year 2000, when it will reach 500 cps and start to increase rapidly. Both models predict the same trend and do not show a divergence until after the year 2005.

These predictions for hard copy terminal print rates are also supported by the print rate per dollar predictions which show a rapid increase starting about 1990. This rapid increase in print rate per dollar (i.e., more output per dollar) will provide the incentive for the increase in widespread acceptance that is predicted for about the year 2000. The state-of-the-art level for print rate per dollar will be around 0.260 cps/$ in 1985 for the Blackman model and around 0.204 cps/$ in 1985 for the Floyd model. It should be noted here that since the last two data points are above the trend curve a faster increase can be expected and this favors the Blackman model prediction. The utilization level of print rate per dollar shows only a very slight increase to around 0.03 cps/$ for both models by 1985 but a more rapid increase starting around the year 2000.

The factor that seems to be producing this trend in print rate and print rate per dollar is the emergence of the non-impact printers. At present they possess the capability for print rates up to 8000 characters per second but these printers are too large for terminals, too expensive, produce

poor quality copies and cannot make multiple copies.[41] All of these problems are being worked on today and their solution should make them the printers of the future.

Second, in the area of hard copy terminal transmission speed, the predictions show a very sharp increase up to approximately 390,000 bits per second (bps) for the Floyd model and up to approximately 495,000 bps for the Blackman model by 1985. Since the last two data points are below the trend curve, the Floyd model prediction seems to be favored. In any case, significant increases are predicted for the 1980's by both models. These faster terminals that are predicted for the 1980's will not be accepted very quickly as shown in the utilization level predictions. These predictions show a very slow rise in transmission speeds up to the year 2000 when transmission speeds will reach the level of 135,000 bps and then the transmission speeds will increase rapidly.

These predictions for hard copy terminals transmission speeds are also supported by the transmission speed per dollar predictions which show a rapid increase starting around 1990. This rapid increase in transmission speed per dollar will provide the incentive for the increase in widespread acceptance that is predicted to start around the year 2000. The state-of-the-art level for transmission speed per dollar will be around 1.5 bits per second per dollar (bps/$) in 1980 and around 5 bps/$ by 1985. The fact that the last

known data point is above the trend curve would favor the Blackman model and its higher predictions. The utilization level of transmission speed per dollar shows only a very slight increase to around 1.5 bps/$ for both models by 1985 but a more rapid increase starting around the year 2000.

In discussion of transmission speed, two points must be made to put the results into perspective. First, the transmission speeds that engineers will build into a terminal are dependent on the transmission lines available. In the 1960's and early 1970's data was sent mostly on telephone lines, regular and special leased lines, which were unable to handle speeds in excess of 9600 bps. Now, with the advent of the new specialized carrier systems, like Datran, transmission speed up to 1.5 Mbps will be available in many areas of the country.[42] Second, terminals must be compatible with the systems of which they are a part. Their transmission speeds must be as fast as the rest of the system if they are to interact with the system. As computers and transmission lines become faster, faster terminals will appear and the predictions show this.

The third point concerns the area of video display terminal display positions. This study looked at the maximum display positions for all video display terminals and determined that there was not a significant trend in this area. Instead it was found that the number of positions has remained constant at 2000 characters per display. This lack

of a trend to build bigger displays is understandable when one notes that the main function of the display is to show segments of data when needed and not to show all the data. For this reason, large displays have not been in demand and the results of this study bear this out.

Lastly, in the area of video display terminal transmission speed, the predictions show a very sharp increase up to around 1.17 Mbps for the Floyd model and up to around 1.5 Mbps for the Blackman model by 1985. The predictions from the Blackman model seems to be favored here because the last known data point falls near the Blackman curve and above the Floyd curve. In any case, significant increases are predicted for the late 1970's and early 1980's by both models. The acceptance of these faster transmission speeds will again lag, and rapid increases of the transmission speeds in widely accepted video display terminals will not appear until the late 1980's and early 1990's, when transmission speeds will reach the level of around 1 Mbps.

These predictions for video display terminals transmission speeds are also supported by the transmission speed per dollar which show that we are in the midst of a very rapid change. Blackman's model predicts transmission speed per dollar values will rise to about 294 bps/$ while the Floyd model predicts values of about 231 bps/$ by 1985. The higher value predicted by the Blackman model seems to be favored here because the last data points fall closer to the

Blackman curve than to the Floyd curve. Again, the utilization level will lag behind and only reach a level of 70 bps/$ by 1985.

This area of transmission speed is the one area in which both terminals can be compared. At present, the video display terminals have faster transmission speeds because the display is faster than the printer, but as print rates increase, the gap should narrow. In hard copy terminals transmission speed of the new terminals has been increasing only slightly in the 1960's and 1970's, but starting around 1980, the increase should become very rapid. The video display terminals, on the other hand, are increasing extremely fast at present and should reach speeds of 1.5 Mbps in the 1980's.

How then can these predictions help a communication manager? From these predictions a communication manager can determine when the technology will have increased to an extent where his terminal is obsolete and will need to be replaced. An acceptable terminal purchased just before the technology increase will cost more and have a shorter useable life than one purchased after the increase had occurred. Also, when a limited budget is involved, predictions like these might aid a manager in determining when to purchase equipment and when to delay purchase. A good example of this is the hand held calculator industry where two calculators can be purchased this year for the price of one purchased last year. Therefore, if a purchase could be put off for a period of time

and a sharp increase in capability or sharp decrease in price is predicted, delaying the purchase could mean significant savings.

In conclusion, this study has looked at hard copy and video display terminals and made predictions based on past trends of the data. If the forces that produced these trends continue, as measured by the trend probabilities, then these predictions will be good. If, on the other hand, new forces are introduced, the predictions will need to be updated to take these new forces into account.

REFERENCES

1. Bright, J. R., Technological Forecasting for Industry And Government, p. v, Prentice Hall, 1968.

2. Bright, J. R., Technology Forecasting, p. 2-3, Pemaquid Press, 1972.

3. Ibid, p. 3-1.

4. Adcock, W. A., "Integrated Electronics", in Technology Forecast for 1980, ed. E. Weber, pp. 111-131, Van Nostrand Reinhold, 1971.

5. Bright, J. R., Technology Forecasting, p. 3-6, Pemaquid Press, 1972.

6. Blackman, A. W., "A Mathematical Model for Trend Forecasts", Technological Forecasting and Social Change, V. 3, pp. 441.

7. Gilfillan, S. C., "A Sociologist's Look At Technical Predictions," in Technological Forecasting for Industry and Government, ed. J. Bright, p. 5, Prentice Hall, 1968.

8. Ibid, p. 446.

9. Alexander, A. J., "Measuring Technological Changes; Aircraft Turbine Engines," Technological Forecasting and Social Change, V. 5, p. 190.

10. Gilfillan, p. 6.

11. Alexander, p. 189

12. Blackman, p. 442.

13. Alexander, p. 190.

14. Floyd, A. L., "A Methodology for Trend Forecasting of Figures of Merit," in Technology Forecasting for Industry and Government, ed. Bright, p. 96, Prentice Hall, 1968.

15. Ibid.

16. Ibid, p. 97.

17. Ibid, p. 98.

18. Blackman, p. 442.

19. Ibid, pp. 449-451.

20. Ibid, p. 443.

21. Ibid, p. 446.

22. Ibid, p. 449-451.

23. Floyd, pp. 96-104.

24. Toulmin, S., "Innovation and the Problem of Utilization," in Factors in the Transfer of Technology, ed. Gruber and Marquis, pp. 24-38, M.I.T. Press, 1969.

25. Ibid, p. 36.

26. Martino, J. P., Technological Forecasting for Decision-Making, p. 6, American Elsevier, 1972.

27. Blackman, p. 441.

28. "All About Typewriter Terminals," DATAPRO 70, THE EDP BUYERS BIBLE, V. 2, Section 70d-010-21A, 1973, and Addendum 1, May 1974, p. 1.

29. Ibid, p. 2.

30. Ibid, pp. 8-20.

31. Ibid, p. 2.

32. Ibid.

33. Zaphiropoulis, R., "Nonimpact Printers," Datamation, May 1973, pp. 71-76.

34. Martin, J., Systems Analysis for Data Transmission, p. 234, Prentice Hall, 1972.

35. Ibid, pp. 232-233.

36. Doll, D. R., "Data Transmission Links - Todays and Tomorrows," The Datacomm Planner, pp. 11-19, Feb. 1973.

37. Martin, p. 234.

38. "All About CRT Terminals," DATAPRO 70, THE EDP BUYERS BIBLE, V. 2, Section 70D-010-20a, April 1974, and Addendum 1, Nov. 1974, p. 1.

39. Ibid, pp. 25-50.

40. Martino, p. 163.

41. Zaphiropoulis, p. 71.

42. Doll, p. 13.

BIBLIOGRAPHY

1. Alexander, Arthur W., "Measuring Technological Change", Technological Forecasting and Social Change, v. 5, pp. 189-203, 1973.

2. "All About CRT Terminals", DATAPRO 70 The EDP Buyers Bible, v. 2, section 70D-010-21a, Oct 1973, and Add. 1, May 1974.

3. "All About Typewriter Terminals", DATAPRO 70 The EDP Buyers Bible, v. 2, 70D-010-21a, April 1974, and Add. 1, Nov. 1974.

4. Blackman, A. Wade, "A Mathematical Model for Trend Forecasts", Technological Forecasting and Social Change, v. 3, 1973.

5. --------, "The Market Dynamics of Technological Substitutions", Technological Forecasting and Social Change, v. 6, 1974.

6. Bright, James R., Technological Forecasting for Industry and Government, Prentice Hall, pp V. -

7. --------, Technology Forecasting, Permaquid Press, 1972.

8. Doll, Dixon R., "Data Transmission Links", The Datacomm Planner, pp. 11-19, August 1973.

9. Floyd, A. L., "A Methodology for Trend Forecasting of Figures of Merit", in Technological Forecasting for Industry and Government, ed. Bright, Prentice Hall, pp. 95-110, 1968.

10. Fuire, Robert A. et al, "Focus on Hard Copy Terminals", The Data Communications User, pp. 23-36, April 1974.

11. Gilfillan, S. C., "A Sociologists Look at Technical Predictions", in Technological Forecasting for Industry and Government, ed. Bright, Prentice Hall, pp. 3-34, 1968.

12. Martin, James, Systems Analysis for Data Transmission, Prentice Hall, 1972.

13. Martino, Joseph P., Technological Forecasting for Decision Making, American Elsevier, 1972.

14. Maser, H. Barry et al, "Focus on Video Terminals", The Data Communications User, pp. 19-32, May 1974.

15. Toulmin, Stephen, "Innovation and the Problem of Utilization", in Factors in the Transfer of Technology, ed. Gruber and Marquis, MIT Press, 1969, pp. 24-38.

16. Weber, Ernst, Technology Forecast for 1980, Van Nostrand Reinhold, 1971, pp. 111-131.

17. Zaphiropoulis, R., "Nonimpact Printer", Datamation, pp. May 1973.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Professor G. L. Musgrave, Code 55Mf Department of Operations Research and Administrative Science Naval Postgraduate School Monterey, California 93940	2
4.	Professor W. L. Creighton, Code 55Cf Department of Operations Research and Administrative Science Naval Postgraduate School Monterey, California 93940	2
5.	Commander Eugene J. Normand, Code 52No Naval Postgraduate School Monterey, California 93940	1
6.	Commander, Naval Telecommunication Command Naval Telecommunication Command Hdqtrs. 4401 Massachusetts Avenue, N. W. Washington, D. C. 20390	1
7.	Chairman, Department of Operations Research and Administrative Sciences Code 55 Naval Postgraduate School Monterey, California 93940	1
8.	Commandant (G-OTM), U. S. Coast Guard 400 Seventh Street, S. W. Washington, D. C. 20590 Attn: LT R. Askey	1
9.	LT Herbert C. Kaler, USN, 306-50-8973/1110 Naval Destroyer School U. S. Naval Base Newport, Rhode Island	1

160572

Thesis
K117 Kaler
c.1 Technological fore-
casts for hard copy and
video display communi-
cation terminals.